AD-A283 575

ITATION PAGE

Form Approved OMB No. 0704-0188

...to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, ...viewing the collection of information. Send comments regarding this burden estimate or any other aspect of this ...form, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson ...fice of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE Aug 94	3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
The Effects of Commercial Compound Bows on Arrow Bullet Deflection

5. FUNDING NUMBERS

6. AUTHOR(S)
Henri C Lambert

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
AFIT Students Attending:
California State Univ

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/CI/CIA
94-115

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
DEPRTMENT OF THE AIR FORCE
AFIT/CI
2950 P STREET
WRIGHT-PATTERSON AFB OH 45433-7765

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

DTIC ELECTE AUG 19 1994 S G D

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release IAW 190-1
Distribution Unlimited
MICHAEL M. BRICKER, SMSgt, USAF
Chief Administration

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Accesion For		
NTIS	CRA&I	☒
DTIC	TAB	☐
Unannounced		☐
Justification		
By		
Distribution /		
Availability Codes		
Dist	Avail and / or Special	
A-1		

14. SUBJECT TERMS

15. NUMBER OF PAGES 100

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500 DTIC QUALITY INSPECTED 1 Standard Form 298 (Rev. 2-89)

94-115

THE EFFECTS OF COMMERCIAL TEMPERED GLASS ON RIFLE BULLET DEFLECTION

A Thesis

Presented to

the Faculty of the Department of Criminal Justice

California State University, Los Angeles

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Henri C. Lambert

August 1994

APPROVAL PAGE FOR GRADUATE THESIS OR PROJECT

GS-13
(7/92)

SUBMITTED IN PARTIAL FULFILLMENT OF REQUIREMENTS FOR DEGREE OF MASTER OF SCIENCE AT CALIFORNIA STATE UNIVERSITY, LOS ANGELES

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ACKNOWLEDGEMENTS

I would like to thank Dr. Allan C. Barrett, Dr. David L. Chapman, and Dr. Anthony Longhetti for their direction and assistance without which this paper would not have been possible.

Special thanks must be directed to TSgt. Richard Estrada, who loaned the rifle used in this experiment; and TSgt. Ron White and all of the members of the Edwards Air Force Base Combat Arms Training branch who provided the range facilities and ammunition for the tests.

This test and my entire Master's education would not have been possible without the aid of the Air Force Institute of Technology (AFIT). AFIT provided me with a year-long assignment to complete my Master's degree.

I wish to thank my mother for teaching me to continuously define and redefine my goals as I moved toward achieving them. I would also like to thank my father for all he taught me about shooting, and reloading ammunition for firearms. It is his instruction, since I was four years old, that allowed me to pursue this study with a sufficient base of knowledge to set-up and conduct this experiment.

My final thanks goes to my wife, Debbie, who encouraged me throughout this project and assisted me with its overall completion with patience and understanding.

ABSTRACT

The Effects of Commercial Tempered Glass on Rifle Bullet Deflection

by

Henri C. Lambert

Since the inception of special weapons and emergency response teams into modern law enforcement units, marksman teams have been employed to provide selective firepower during contingency operations such as barricaded suspects and hostage situations. During these operations, police marksmen are frequently confronted with storefront commercial tempered glass, a significant obstacle that may deflect bullets in an unpredictable manner. This study was conducted in order to explore and quantify the deflection, stability, fragmentation, and lethality of the .308 caliber, full metal jacketed bullet. In a classic experimental design, the researcher determined the minimum stability distance of the round when fired through glass. This distance allows marksmen to know the closest distance they may fire a bullet through tempered glass without significant loss in accuracy. The experiment also quantified and plotted deflection at various distances and glass angles in order to create a table of deflection for when marksmen encounter tempered glass. Through a mathematical model derived and adapted from an equation, created previously by the U.S. Army Medical Department for quantifying energy loss by projectiles penetrating tissue, the author evaluated a method of predicting deflection. This method was compared with experimental test data using the Wilcoxon method in order to determine its accuracy.

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CHAPTER 1

Introduction

Since the inception of special weapons and emergency response teams into modern law enforcement units, marksman teams have been employed to provide selective firepower during contingency operations such as a barricaded suspect or hostage situation. In the event that negotiations with a suspect break down, marksman teams can provide a hostage with his or her only chance to live. Employing the use of a well-sighted rifle, marksman teams have the capability to eliminate the threat with surprise, effectiveness, and without endangering the lives of other law enforcement personnel or the hostage. However, if employed without significant knowledge of the mediums the projectile must interact with, the marksman can miss the suspect entirely and become the catalyst for a massacre. One such medium is glass. Marksman teams are taught not to make a shot through glass unless they have a straight-on-shot and the target is close to the medium. If they are required to make a shot at an angle, it is usually recommended that the team consider using one shot to remove the glass and another to hit the suspect; a process called simultaneous engagement (Plaster, 1990). However, this method requires excellent timing and must ensure that the extra round does not penetrate other hostages. An additional unknown is the effect of secondary projectile glass that can become lethal after being penetrated by a bullet. This is because little is known about the resulting trajectory of bullets fired at angles through glass. It is rare when an incident requiring a marksman team is outdoors. Incidents are normally inside commercial or residential properties where a suspect attempts to barricade himself or hide. While setting up at these locations,

marksman teams must ensure they have cover and concealment. It is rare when one can find both in a location which offers a straight-on shot through all windows where the suspect might appear. One would assume that it would be beneficial for a marksman to predict the behavior of a bullet which might have to be fired at an angle through glass where the hostage is only inches away from the intended target.

If marksman teams cannot be deployed in a manner where they can provide selective firepower through a window, without the threat of bullet deflection, the marksman must know how glass at an angle affects bullet trajectory. Previous experiments with a .38 cal. revolver and .233 in. tempered glass (Thornton and Cashman, 1986) revealed that glass at an angle has a significant impact on bullet trajectory and concluded that it is unknown how glass might affect high kinetic energy bullets such as a high velocity rifle bullet.

During several field trials by police agencies, police marksmen discovered that glass angle has a significant effect on rifle bullet deflection. During trials, marksmen completely missed intended targets that were under 10 yds. distant when firing through glass. These tests also suggested that glass distance might play a factor in bullet accuracy. Marksmen observed that shots made close to the glass surface produced extraordinary deflections of the bullet. Although these tests did not quantify deflection scientifically, they did expose the elements of research for this study (Albanese, Moody, & Rayl, 1982; and Sanow, 1992).

This study was undertaken to produce a tabular and mathematical model of deflection for the .308 caliber bullet fired through 1/4 inch-thick tempered glass. These models were developed through classic experimentation, with rigorous

controls for human error. The data recovered have been placed into tables which reveal the relationship between bullet stability and distance; and deflection, distance, and glass angle.

The present study utilizes Form and Style (1990) as the style source and is formatted using the guidelines of the American Psychological Association.

The author wishes to remind the reader that his intent is not to glorify the mission of the police or military marksman team. These teams are trained to be a last resort tool should negotiations fail. Negotiations are the hallmark of police attempts to neutralize any volatile situation. However, occasionally negotiations fail due to a suspect that is mentally unstable or determined not to surrender. It is on these occasions that the marksman team or special entry teams can rescue a hostage that would otherwise face certain death. At these times a marksman team must be able to engage the target with certainty that they will save the hostage.

Statement of the Problem

Following a thorough review of the literature involving training manuals, scientific and professional journals, police agencies, and computer searches, the author found that little is known about predicting the trajectory of bullets through glass; particularly that of the .308 caliber rifle bullet most commonly used by police marksmen. Currently, there is no available method to allow marksmen to predict the effect glass has on the trajectory of a rifle bullet. Without a table of deflection values or method of calculating bullet deflection with respect to glass angle, shooting through glass is inaccurate at best.

This study focuses on the following subproblems:

1. What relationship does distance have on the stability of the .308 caliber bullet?

2. Does a high mass, low deformation bullet deflect less than a low mass, high deformation bullet?

3. What is the relation between glass angle and bullet deflection?

4. Can a mathematical model be produced to predict bullet deflection through glass?

Purpose

This study was conducted to determine the effect of commercial tempered glass, at varying angles, on the trajectory of the 7.62-mm. (.308 cal.), rifle bullet. The analysis of uniformly collected data provides a means of predicting bullet trajectory following its passage through glass.

The first part of the study was conducted to determine the minimum distance the bullet can be fired at tempered glass before the bullet becomes unstable. In order for a bullet to become ballistically stable, it must reach minimum velocity and undergo enough rotations to prevent the bullet from tumbling after impact with the glass. This longitudinal instability or yaw decreases with distance; however, it can still be as high as two degrees after 100 yards of flight (DiMaio,1985, 46)

The second part of the experiment was conducted to determine the effect angle has on bullet deflection. All shots during this phase were accomplished beyond the minimum distance that the bullet is stable.

The third phase compares the deflections of the .308 caliber full-metal-jacketed round, with deflections from previous studies to determine if the jacketed round is deflected less than soft point or hollow point rounds.

The fourth phase of the experiment was conducted to determine whether a mathematical model can predict the effect glass angle has on the deflection of a particular known bullet type given the thickness and density of the glass.

Significance of the Study

On April 4, 1991, four Asian males took over a Good Guys electronics store in Sacramento, California. During the incident, the suspects bound several hostages and placed them against the glass in the front of the store to discourage policemen from shooting. Outside, the Sacramento County Sheriff's Department, Special Enforcement Detail (SED), had to set their marksman at an angle to the storefront glass to prevent him from being seen and allow negotiations to take place in the parking area in the front of the store. Following the shooting of several hostages, the team was ordered to assault. The signal to begin the assault was for the marksman to take out one of the suspects with a head shot. The marksman chose to initiate when one suspect could be observed through an open door at the front of the store. There was just enough space between the hinge area of the open door to hit the suspect without encountering either the door frame or the tempered glass which covered the entire store front. As the marksman squeezed the trigger, the suspect allowed the door to shut. A perfect shot was destroyed when the bullet enconntered the glass at an angle. This angle was enough to deflect the bullet completely away from the suspect. The suspect was pelted with glass fragments which momentarily startled him and then he began to

execute hostages. The suspects succeeded in executing three hostages and wounding 11 before the rest of the team could neutralize the incident. Although the marksman may have made the proper choice to prevent any deflection of the bullet by shooting through the gap between the door frame, a firm knowledge of bullet deflection through the glass might have allowed the marksman to reposition for the best possible shot or predict the effect the glass might have on the bullet. In this case lives might have been saved (Marlow, 1991). A subsequent conversation with John Marlow (1994), a journalist closely associated with members of the team that conducted the operations that night, revealed that glass is a formidable problem for special weapons teams. He mentioned that they attempt to completely avoid it if at all possible. If glass can not be avoided, the teams either attempt to clear the glass manually before taking a shot or is given the opportunity to fire through it only if the suspect is very close to the medium. Without these conditions, the team are not given the "green light" to engage. Marlow encouraged study into bullet deflection through glass and requested a copy of the results of the present study.

Several field tests were conducted by police agencies to discover the magnitude of bullet deflection. During these tests, marksmen conducted single shots at several glass types at a variety of angles. These tests all found significant deflection of bullets following impact with glass. They also discovered that shots accomplished close to the glass resulted in bullet instability where the bullet completely missed the target. They found that there must be a minimum stability distance for bullets. All shots must be made beyond this distance in order to be accurate. These studies utilized soft and hollow-point ammunition which always

fragmented upon impact. However, soft-point ammunition fragmented and deflected less than hollow-point ammunition. This leads to the theory that full-metal-jacketed ammunition will fragment less and produce minimum deflection values. Each study recommends further investigation of the effects of bullet deflection through glass (Albanese, Moody, & Rayl, 1992; Sanow, 1292).

In a telephone interview with Mike Albanese (1994) of the previous study, he relayed that their study was unscientific in nature and revealed the need for more information about deflection and glass. He elaborated that his team, the Los Angeles Police Department, Special Weapons and Tactics Platoon, would not attempt a shot while close to glass as a result of their findings with shots fired close to glass. He suggested that research into this area might provide a way to allow shots to be made closer to the glass medium.

These aforementioned studies and incidents have resulted in limitations to police marksmen. These marksmen are intended to provide an added depth of response for police contingency teams. However, without the capability to predict deflection though glass, these teams are ineffective. Glass is their most common obstacle when responding to urban incidents, particularly 1/4 inch-thick tempered glass. This glass is encountered in all storefronts and mall shopping areas.

Because of the expense of tempered glass, many law enforcement units are not able to afford to routinely practice glass shots. Of the departments contacted, all mentioned that the only glass they encounter is when they are given a recently decommissioned bus or vehicle to practice with. The creation of a table of deflection values would allow any marksman team to select the most appropriate location to employ selective firepower and determine and minimize the effects of

glass. It is also hoped that the resulting data could be used to assist investigators in the reconstruction of crimes involving bullets fired through glass.

Knowing the minimum stability distance of the bullet will allow marksmen to ensure that all shots are made beyond this distance, guaranteeing maximum accuracy of the bullet. It is possible that a marksman will have to engage a target from behind a glass medium. A suspect holding a hostage within a shopping mall might require a team to set-up within an adjoining store, forcing the team to make a shot while close to the storefront glass present in all malls. It would be impossible for marksman to break out the glass without giving their position away.

Producing a mathematical model for predicting the deflection of bullets through glass will allow marksmen to predict deflection for any caliber bullet and any weight bullet. Experimentation with expensive glass could be minimized, saving hundreds of dollars per experiment. Forensic scientists could also utilize this formula to predict bullet trajectory for shootings involving glass, and reconstruct approximate bullet calibre and ballistic coefficient for shootings where the bullet is destroyed.

Theoretical Framework

This study is based on the experimentation of Harper (1939) who only studied shots fired at 90 degrees; Stahl, Jones, Johnson, and Luke (1979) which was concerned with the wounding effects of bullets fired through glass; and Thornton and Cashman (1986) who tested only .38 cal. bullets fired through glass at varied angles. In these studies, glass was mounted in a frame, and a revolver was fired at uniform distance while the glass was rotated at several angles. A paper target was placed behind the glass to allow the deflection of the bullet to be

measured. The deflection was calculated by measuring the distance of bullet impact from the aim point. By using this distance and the uniform distance of the paper from the glass, the angle of deflection could be measured readily. The integrity of the bullet could be determined by examining the hole produced upon the paper target. A ballistically viable bullet would impart a nearly circular clean hole while a damaged or tumbling bullet would leave a jagged or oblong hole in the target.

Albanese, Moody, and Rayl (1984) found that bullets fired at 7 inches from the glass pane produced a near random deflection of bullets. These bullets completely missed targets that were only five yards beyond the glass. When they continued firing from a greater distance, 50 yards, the bullets hit the target. They suggested that this relationship should be explored further. This study will attempt to quantify the minimum stability distance for the .308 caliber full-metal jacketed round by measuring the size of a three-shot group placed through glass at a 45 degree angle of incidence at varying distances. It is assumed that the greatest operational angle for close glass shots will be 45 degrees. This angle will also produce the greatest deflection for this range from 0 to 45 degrees angle of incidence. The minimum stability distance is reached when the rifle is fired far enough away from the glass to produce a three shot group that falls within a five-inch circle on a target placed five yards beyond the glass. A five inch circle is small enough to ensure that a head shot or shot to a vital area of the anatomy will be achieved.

In addition to utilizing a test model, bullet deflection should be able to be mathematically calculated using a relationship similar to Snell's Law. Snell's law

(Zafiratos, 1985, 486-487) allows one to measure the refraction of light through glass by taking into account the ratio of the speed of light in glass and air with respect to the angle of incidence of the light to the glass.

N = Velocity of Light in a Vacuum/ Velocity of Light in Medium

For air, N = 1.0003 or effectively, 1

For glass, N = Vglass/Vair

For passage of light from air through the glass, Snell's Law becomes:

SIN (incident an ‹ (1) = (Nglass) x SIN(deflection angle)

SIN(deflection angle) = SIN(incident angle) x Vair/Vglass

This principle cannot readily be adapted to the path of bullets because the speed of light in the medium is constant where a bullet will decelerate during penetration. This deceleration is affected by the drag created by the bullet's shape (ballistic coefficient) and the density effect of the medium. We would expect that a dense material such as metal would have greater effect on a projectile than a material of lesser density such as glass. In addition, the thickness of the medium would have to be taken into account in order to predict how much deceleration will be created as the projectile negotiates the medium. Furthermore, projectiles lose energy through deformation, further complicating the application of Snell's Law. Through research, however, the author has uncovered a method which might allow the measurement of all of these variables to be taken into account.

During World War II, the United States Army Medical Department conducted hundreds of experiments with cadavers and ballistic gelatin to gain a better understanding of how missiles affect the human body and how to better develop armor to protect it. During these studies, experimenters found that the

best projectile for penetration through a medium is one that has maximum mass and minimum cross sectional area. Using this model, the most optimum sniper bullet for encountering glass would be one that is of high mass and has the least chance of deformation such as a full-metal-jacketed bullet. The research also revealed a relationship between bullet energy (E), medium thickness (S), density of the medium, mass of the projectile (M), ballistic coefficient (Cd), and the frontal cross sectional area of the projectile (a). This relationship was used to predict a bullet's change in energy as it passed through a bone, gelatin, or other medium (Beyer, 1962, 121, 225).

$$E = Eo \times e\text{^}{-2} \times \Delta \times S \qquad \text{Where } \Delta = \text{Density} \times a/m \times Cd$$

Through mathematical calculation, this formula can be manipulated for an adaptation of Snell's Law. The thickness of the medium with respect to the bullet changes with the angle of incidence. Therefore:

$$S = T/\text{COS (Incident Angle)} \qquad T = \text{Glass Thickness}$$

$$\text{Frontal Area of Bullet} = a = 3.14159 \times (\text{Bullet Caliber}/2)\text{^}2$$

Further manipulation allows the equation to be plugged into Snell's equation:

$$E = Eo \times e\text{^}{-2} \times \Delta \times S \qquad Eo = \text{Initial Energy} \quad E = \text{Energy after glass}$$

$$\text{Index of Refraction for Bullets} = E/Eo = e\text{^}{-2} \times \Delta \times S$$

Plugging this into Snell's equation,

$$\text{SIN(deflection angle)} = \text{Index of Refraction} \times \text{SIN(incident angle)}$$

$$\text{SIN(deflection angle)} = e\text{^}{-2} \times \Delta \times S \times \text{SIN(incident angle)}$$

Introducing the value for S and using deflection angle = d, and incidence angle = i

$$\text{SINd} = e\text{^}{-2} \times \Delta \times T/\text{COSi} \times \text{SINi} \qquad \text{SIN/COS} = \text{TAN}$$

$$\text{Deflection Angle} = \text{INVSIN}(\text{TANi} \times \Delta \times T/e\text{^}2)$$

Therefore, the relationship of bullet deflection can be quantified using the application of Snell's Law. This application should be generalizable for all bullets that are not deformed significantly by the glass (full-metal-jacketed). By using the manufacturer's value of Cd and the application of this formula, observed values and computed values of deflection can be compared to reveal the generalizability and applicability of the formula for deflection.

Hypotheses

1. For distances under 100 yards, bullet stability increases as target distance increases.

2. A high mass, low deformation bullet (full-metal-jacketed) will be deflected less than a lower mass, high deformation bullet (soft or hollow-point).

3. While target distance is held constant, bullet deflection increases predictably with angle of incidence.

4. A mathematical model using Snell's Law can predict the deflection of bullets through glass at an angle.

Limitations

The following factors are considered limitations to the accuracy of the present study.

The capability to effectively anchor the rifle to the bench in order to standardize each shot will have a direct imoact on the accuracy of results of the experiment. This error would be more pronounced while using a short-barreled firearm such as a pistol. However, a rifle that is bench rested provides a significant degree of accuracy. It is assumed that the use of three shots for each angle will dampen the effect of this error.

The dimension of the glass for this study was limited to one-foot square sections. Although most storefront windows are larger, due to cost limitations, glass size must be limited. Thinner glass, such as that encountered in homes, flexes or bows considerably more than thicker glass. This fact can be readily measured by pushing in the center of a large home window and comparing the flexion with that of a 1/4 inch tempered window of a storefront. It is assumed that the use of smaller dimension glass for the thicker tempered glass will not affect bullet energy loss or deflection. In addition, the use of square glass will ensure that uniform tension is applied when the geometric center of the glass is struck.

Deflection is evaluated using three rounds due to the expense of glass. Although a mean deflection would be more accurate using 20 or more panes, Sanow (1992), and Thornton and Cashman (1986) found that three rounds provided a sufficient mean. Thornton and Cashman's experiment utilized a pistol which is considerably less accurate than a rifle and found that three iterations were sufficient to establish statistical significance, while Sanow used a rifle and found three rounds provided an accurate mean. The considerable accuracy of the rifle and the uniformity with which it will be used minimizes the effect of using only three rounds.

Deflection was measured at three uniform distances from the glass. This evaluation should be sufficient to generalize for all ranges between 100 yds and the minimum stability distance since the .308 bullet experiences an average of 500 foot pounds of energy and 300 feet per second loss between 0 and 100 yards. This accounts for a 19 percent energy change and an 11 percent velocity change across that distance. Decrease in energy might increase deflection; however, the

accompanying decrease in yaw with increased distance will have a mitigating factor on changes in deflection (Remington, 1987, 41).

Delimitations

The following factors are considered limitations to the experiment that are beyond the control of the researcher.

Minor variations, due to the manufacturing process, of the bullet, including projectile weight, powder charge, and bullet hardness are considered. However, due to high accuracy standards, most ammunition companies offer a uniform product. This experiment utilizes the 7.62mm (.308 calibre) M-118 Special Ball cartridge. Designed specially for sniper use, this ammunition type is manufactured for an extreme spread of less than 12 inches for a ten-shot group fired at 550 meters in a test cradle (TC 23-14, 1989, 2-26).

Minor variations in the glass such as thickness, density, and tensile strength are inherent to the manufacturing process. However, density and thickness will be measured directly during the test phase to ensure quality results. All of the glass purchased for this experiment was acquired from the same manufacturer and manufactured at the same time using the same equipment. This required that all pieces be rolled through the same rollers to ensure uniform thickness and that the glass material was from the same batch. All glass panes were measured for thickness, and all were found to be .2344 in. thick.

Minor variations in the plywood density might result in penetration and cause a bullet to be identified as lethal when it is not. However, three repetitions should minimize this effect.

Minor variations in trigger squeeze due to the human factor of this study might affect initial impact of the bullet against the glass. However, all initial three-shot-zeroes were measured prior to conducting glass penetrations. It is reasonable to expect that no penetration was outside the range of the three-shot-zero from the center of the glass.

Assumptions

Glass thickness, density, and internal properties are considered constant throughout all panes acquired. Density and thickness was measured for three samples and averaged to determine the appropriate value for the study.

For the mathematical model, it is assumed that bullet angle does not change once it completes its transition through the glass and enters the air beyond. All angle changes are imparted by the glass medium alone.

Three shots are sufficient to determine mean deflection. This assumption is supported by Thornton and Cashman (1986), and Sanow (1992).

Bullet mass and internal properties are the same for all ammunition of the same type and manufacturer.

A lethal round is one that penetrates a 5/8 inch piece of plywood following passage through the glass (Sanow, 1992).

The mathematical model has application only beyond the minimum stable distance since rounds fired within the minimum stable distance are unpredictable.

CHAPTER 2

Review Of Literature

Conduct of the Review

In order to uncover all previous research and related literature in the study of the effects of bullet trajectory through glass, an in-depth review of literature was conducted.

The author first conducted a search in applicable textbooks in forensic science. As a secondary source, these texts are an excellent reference for ballistics information and glass technology since both bullets and glass are frequently found as physical evidence. Although a majority of texts restricted their breadth of knowledge to glass fracture and basic principles of firearms identification, Di Maio (1985) provides an entire subchapter on intermediate targets and their effects on bullets. These targets include bone, glass, wood, and metal. The text is restricted to describing some of the mechanics involved in penetrating intermediate objects and reveales how little is known about this area of study.

With four years experience as Officer-In-Charge of a small United States Air Force Emergency Services Team (EST) and as a graduate of the California Department of Corrections 27th Special Emergency Response Team (SERT) Academy, the author collected numerous articles, after-action reports, and manuals associated with special weapons and tactics. Unfortunately, a search of applicable police, military, and California Department of Corrections literature revealed no guidance about marksmanship techniques when encountering glass. The after-action report for the Sacramento, California Good Guys electronics store was recovered. This report reveals how hostages died as a result of a marksman's

accidental encounter with glass and provides one solid example for the need to study glass as an intermediate target (Marlow, 1991). In addition, contact was made with colleagues at the Los Angeles Police Department, Special Weapons and Tactics Platoon; Los Angeles County Sheriff's Department, Special Enforcement Bureau (SEB) Gold Team; and USAF Combat Arms Training and Maintenance (CATM), Edwards AFB (two members are recent graduates from the Federal Bureau of Investigation Sniper Course held at Camp Pendleton, CA.). During these contacts, two significant studies involving the impact of bullets and glass were uncovered and will be reviewed in the next section (Albanese, Moody, & Rayl, 1984; Sanow, 1992). Discussions with members of the aforementioned groups revealed that glass, although a common media during hostage and contingency operations, is not yet understood. Snipers are taught to attempt to remove glass as an obstacle by a preemptive shot or to ensure that targets are close to the medium when making the shot. Marksmen are aware that glass, depending upon its thickness and internal properties, can deflect bullets with disastrous results. During a telephone conversation with Mark Albanese (1994), he mentioned that his team, even after his 1984 group study, does not attempt to make shots through glass unless no other option is available. As a result of these conversations with internationally recognized teams that make numerous weekly responses in their field, the author concluded that this area deserved further attention.

The quest continued with a manual search of appropriate indexes of criminal justice and forensic science. A search of the Criminal Justice Periodic Index from October 1980 to September 1993, and Criminal Justice Abstracts from 1968 to

1993, revealed three related studies (Harper, 1939; Stahl et al., 1979; Thornton & Cashman, 1986). The most recent cited only the other two as references, concluding that the others were the only scholarly literature in the area of study. Harper's study cited no other articles and Stahl's study, concerning medical aspects of bullets and glass, cited only a few medical and forensic articles concerned with distance determinations using powder patterns. Review of these articles revealed nothing regarding bullet deflection.

In order to find other possible incidents of shootings involving glass, a CDROM search of newspaper articles of California police-involved shootings was conducted. One hundred fifty four articles were reviewed before February 1, 1994 and revealed only the Good Guys incident in Sacramento.

An additional search of all government publications by computer and contact with the U.S. Government Printing Office, Washington D.C. revealed an excellent source which is the exemplar for any study treating the passage of bullets through intermediate targets. This source is Wound Ballistics (1962) and provides the mathematical foundation for this study.

In order to gather all related literature which were even remotely related to the subject at hand, the author conducted an on-line search of the following databases: LEXUS/NEXUS, CARL, ERIC, DIALOG, NCJRS, Social Science Search, MEDLINE, MEDLARS, and DAI. The terms of search included: glass fragmentation, wound ballistics, firearms and glass, intermediate targets, bullets and glass, projectiles and glass, and barriers and weapons. This search produced 75 abstracts which uncovered only one related resource that had not yet been revealed (Sellier, 1977). The remaining sources were articles or books regarding:

evaluation of gunshot residue on glass; identification of entrance and exit holes through glass; evaluations of bullet resistant glass by penetration only, without any angle or mathematical treatment; or the value of bullets or glass as evidence in forensic investigation.

I believe that all possible sources of literature have been revealed regarding the effects of glass on bullet trajectory. If other sources do exist, they have not yet been published.

Previous Research

Several previous studies on the effects of bullets and glass have been conducted. These studies can be placed into two categories: quantitative and qualitative.

The first category is that of scientific quantitative studies. These studies were conducted to investigate bullet deflection following the passage through glass and attempt to quantify it numerically. While conducting these tests, researchers utilized precise research methodology and ensured that all shots were standardized with multiple rounds being used to complete measurements. The resulting data were reliable and were placed into tables and are reproducible.

The second category includes qualitative studies which were conducted in order for the researchers to establish whether bullets deflect while passing through glass. These studies were conducted under non-standard conditions and usually employed firing only one round at a given configuration and utilizing a number of different ammunition types. These studies provide an insight into the possible quality of performance of varying ammunition types and how they perform when

penetrating glass. In these studies, deflection was not measured; it was reported that it appeared to occur or not to occur.

Quantitative Studies

Harper (1939) provided an insight into the mechanisms which affect bullet trajectory when passing through glass. In his study, the first of its kind, he established that bullet trajectory was affected by bullet deformation, loss of energy, and deflection emparted during passage through the glass. Deformation of the bullet destroys the bullet's stability that is created when it spins. The resulting non-uniform shape induces wobble and prevents it from being effective upon passage through subsequent targets. The loss of energy that the bullet experiences as it passes from air into the very dense medium of glass can significantly change the bullets velocity. This velocity change can create deflection and therefore change the trajectory of the bullet.

Harpers study states that there had been no previous attempts to quantify deflection through glass. He proposed to explore the effects of 3/32" and 1/4" plate glass, together with automotive safety glass (a sheet of plastic sandwiched between two sheets of glass), on the trajectory of .38 caliber lead, 38 caliber metal cased, and .357 caliber metal piercing-tip ammunition. The same revolver was used for each round fired. This pistol was not placed in a bench rest. However, a preliminary test was conducted without glass, and the shooter produced only a 1.5 inch group at 25 yards. The glass was placed in a full-framed mount and moved standard distances from the shooter toward the target, which was at a distance of 25 yards. At each position, 20 rounds were fired through the glass, and the deflection of each round was measured. The glass was progressively moved

toward the target, decreasing the glass-to-target distance and increasing the muzzle-to-glass distance. It is assumed that several shots were made through each window since the author mentioned that glass was at a premium. In addition, tempered glass, which completely shatters upon penetration, had not yet been invented. This procedure was repeated for each bullet type. The deflection values were measured for each position and averaged to produce a mean deflection value. These values were placed into table format to establish the effects of the glass. The table of deflection vs. glass-to-target distance revealed several important facts. First, higher energy bullets tended to be deflected less than lower energy bullets. Second, lower energy bullets tended to produce curvilinear relationships while the higher energy bullets produced more linear relationships between deflection and glass to target distance. In addition, all bullet holes in the target revealed that the bullets had tumbled because they left oblong "keyhole" puncture marks. The bullets were recovered using bags of sawdust and nearly all were significantly deformed. Harper mentions that the bullets were deflected off of the target when any addition of glass angle was made.

A subsequent test by Stahl, Jones, Johnson, and Luke (1979) attempted to evaluate the degree of bullet deformation produced by only 1/8 inch tempered glass. This test was warranted following the arrest of a man who claimed he had shot a burglar through the window of his house. The coroner could not believe the bullet had been deformed by the glass and concluded that the bullet-wound was one of contact because it was stellate in nature. The bullet had been nearly completely destroyed by the thin window. In an attempt to support the claims of the suspect, the research team fired identical bullets through identical glass into

gelatin in order to prove the extent of deformation. Using a 158 grain, solid-lead, .357 caliber bullet, they found that all of the bullets were deformed by the glass into a stellate form. They also discovered that as the muzzle to glass distance increased, the glass fragmentation into the target was reduced. Although no attempt was made to determine the deflection of these bullets, it is important to note that even a minimal thickness of glass can produce significant deformation of a bullet. The team suggested that further research be conducted to explore the effects of glass on bullet trajectory.

In response to a similar event involving the shooting of a burglar through the 30 degree angled window of his car, Thornton and Cashman (1986) attempted to conduct the first study of the effect of glass angle on bullet deflection. The researchers emphatically state that aside from the two previously mentioned studies, no other research had been conducted. The team used 14 sheets of 1/4 inch tempered glass for their study. The glass was mounted in a full frame at 30 degrees to the vertical axis and shots were made through the glass as it was rotated about the horizontal axis at 90 and 70 degrees approach angle. Glass-to-target distance was held constant at 100 cm. The study employed 125 grain lead and 156 grain jacketed hollow-point .38 caliber bullets. Deflection was measured for each round with only three rounds being fired for each angle (termed sufficient to establish a mean deflection by the researchers). The deflection values were subjected to a two-tailed t-test to establish whether the introduction of multiple angles, 30 degrees vertical and 70 degrees horizontal, would produce any effect on deflection. An additional t-test was conducted to observe whether separation of the jacket of the hollow pointed rounds compared with the non-jacketed lead

rounds produced a significant difference in trajectory. The mean deflection of the core compared with its jacket was made, and the resulting deflections were compare to the un-jacketed lead bullets. The t-tests showed that multiple angles do produce a deflection difference of .05 significance, and that jacket separation produces a difference of .05 significance on deflection compared to single angle and unseparated bullets respectively. This study is considered important because it not only establishes that tempered glass at angles produces significant deflection of bullets (an average of 10.7 degrees for the 90 degree approach angle). In fact, the researchers mention that in this case, one would have to aim at a person's head in order to hit them in the heart. It also establishes the importance of maintaining only single angle measurements of deflection and the importance of jacket separation on deflection. The authors concluded that it was unknown how glass might affect high energy rifle bullets and that further research was in order. The author contacted Dr. Thornton (1994) by telephone in order to discuss the present experiment. Dr Thornton agreed with the test method and encouraged contact with Dr. Ferdinand Rios. Dr Rios conducted a similar test of bullets fired through metal plate. Dr. Rios (1994) agreed with the premise and set-up of the present experiment. Rios' data reveal that deflection at a 90 degree glass angle consistently produces a slight right deflection of the bullet (1990, 85) where fully-jacketed right-hand twist bullets fired through metal plate consistently deflected to the right at 90 degrees (measured as 0 degrees in his study). Rios' study also mentions that bullets appear to be affected in the same manner as light photons in that intermediate targets also create a type of refractive index whereby bullet paths are bent as they pass through the medium; however, they are also affected by mass,

ballistic coefficient, and medium (p105, 109). He suggests research into this area. Rios' study was uncovered after the data for the present study were collected. However, his study, an attempt to predict deflection through steel plate using curve-fit and regression, provides no conflicting data; only further support for the premise of the present study.

Sellier (1977, 123) conducted research involving 9mm bullets fired through 6mm glass at varying angles. Although deflection was not measured, the bullets recovered following passage through the glass were significantly deformed even though they were fully jacketed. It must be noted, however, that these were low velocity rounds. It is not known whether high velocity rounds will deform as significantly. During a previous work (1969, 238), Sellier discovered that the angle of entry of a bullet could be measured by dividing the caliber of the bullet (a) by the largest measure of an oblong hole (b). This value (a/b) is equal to the SIN of the entrance angle. This study will use this relation to quantify the degree of tumble of bullet following passage through glass.

The first research involving rifle bullets and their interaction with glass was conducted by Sanow (1992) as a result of the deflection of a bullet through tempered glass during a failed hostage rescue attempt in Sacramento, California. Although Sanow mentions no previous experience with forensic/ballistic research, his study was well planned and executed with strict adherence to scientific method. In his study, he tested six .308 caliber bullet types: 180 grain Nosler Partitioned Soft Point; 165 and 180 grain Pointed Soft Point; 168 and 180 grain Hollow Point Boat Tail; and the 220 grain Round Nose Soft Point. These bullet types were fired through 1/4 inch tempered, plate, and dual pane glass. The glass was placed at 55

yards muzzle-to-glass distance with the overall muzzle-to-target distance of 60 yards. The glass was placed in a rigid wooden frame and placed at angles of 90 and 45 degrees to the line of fire. The rifle was placed in a bench rest and an initial 3-shot group was taken and averaged without the glass in order to establish the aim point. The target was b27 target paper followed by a 5/8 inch sheet of plywood. Deflection was measured for each round, and bullet stability and integrity were measured by evaluating the holes produced on the paper. Bullets which produced "keyhole" punctures had tumbled and multiple punctures, which were not caused by glass fragments, were evaluated for number of fragments. Bullets were termed lethal if they continued to penetrate the 5/8 inch sheet of plywood following passage through the glass. It is important to note that all bullet types were soft point or hollow point. The study revealed that all of the bullets tumbled following passage through the glass and all fragmented. The tempered glass produced deflections of up to 1.8 inches at 90 degrees and 5 inches for the best performing bullet (Nosler Partitioned Soft Point) at 45 degrees. A further test with gelatin at 90 degrees showed that the partitioned soft point had 55 percent deformation following passage through the tempered glass. This study is relevant to the present because it establishes that bullets with greater jacketing not only fragment less, they produce less deflection through glass. It provides a basis for the assumption that a full-metal jacketed round would provide the best performance through glass. Finally, it establishes that tempered glass does have a significant effect on the trajectory of the .308 rifle bullet.

Qualitative Tests

DiMaio (1985, 47) conducted a study to determine the effectiveness of full-metal jacketed military bullets. He noted that all round-nosed and hollow pointed bullets deformed and fragmented in gelatin while full-metal jacketed ammunition did not. In fact, during a test of 34 jacketed bullets, only six partially fragmented. Additionally, of twenty, 7.62 x 51 mm (.308 caliber) bullets, only three partially fragmented. In a comparison of jacketed ammunition, he states that the .308 caliber round is also better suited for penetration because it tends to deform from the tip or cannula while others extrude the core out of their bases, making their tips deform into flat ribbons. This factor prevents the .308 caliber round from expanding.

Marksman tend to favor soft-point and hollow-point ammunition for contingency operations because these rounds expand quickly upon contact with tissue. Expansion and deformation ensure a debilitating shot to a suspect and prevent over-penetration to another hostage. However, as was demonstrated by Sanow (1992), these rounds fragment and deform quickly when they encounter glass. The most desirable round for glass penetration would be one that does not deform such as an armor piercing or full-metal jacketed round. An armor piercing round would be completely out of the question. These bullets are made out of depleted uranium or steel and would most definitely not deform. However, they would over-penetrate several structures beyond the target. It is not known whether jacketed ammunition would deform through glass, although one study did find that jacketed bullets did perform well through glass.

Albanese, Moody, and Rayl (1984) acquired pane, tempered, laminated, security, and bullet-resistant glass from a manufacturer and conducted several shots with .38, .45, .223, and .308 caliber ammunition. Additional shots were made with 12 gauge ammunition. The intent was to observe whether the bullets would penetrate certain types of glass at 30, 45, and 90 degree angles. For the study of .308 caliber ammunition, the team used 150 grain full-metal jacket and pointed soft-point. All configurations used only one round, and no attempt to make a three-round zero was made because this test was not conducted to measure effectiveness, but simply to observe whether marksman could hit their intended target, a mannequin. During several shots made near the glass, the team found that rounds completely missed the target, which suggested further study to determine how far a marksman must be from the medium in order to allow the bullet to stabilize enough to penetrate with accuracy. They did find that the jacketed rounds resulted in accurate shots on the target with little observable deflection. The team did not attempt to recover bullets which entered the mannequins in order to determine whether they tumbled following penetration or were deformed. Also, the study did not determine fragmentation of the bullets, only that glass fragments surrounded bullet holes, so it is unknown whether glass fragments were mixed with bullet fragments. However, the mere fact that the jacketed round did perform well when fired at a distance from the glass provided evidence that a jacketed round would provide the optimum projectile for glass. If it could be further determined that the round was not lethal following a second penetration into tissue, the jacketed bullet would be safe from over-penetration.

The Sanow study utilized penetration of a piece of 5/8 inch plywood to determine that rounds were lethal. This procedure will also be used in the present study.

In a subsequent conversation with Michael Albanese (1994) the author attempted to determine if elements of the previous study by Albanese, Moody, and Rayl (1984) were left out of the article. Such elements as measurements of deflection, stability, deformation, or tumble were considered. He relayed that the study was not scientific in nature and should not be used as evidence to prove anything. However, he felt that it provided an excellent basis for establishing jacketed .308 caliber ammunition (ball ammunition) as the optimum for glass penetration. He mentioned that his team, Los Angeles Police Department Special Weapons and Tactics Platoon , now carries ball ammunition for contingency operations involving glass. He further stressed that shots made close to the medium were not accurate and that study into this area would be beneficial for special weapons teams.

A further review of DiMaio (1985, 46) provides insight into the possible cause of inaccuracy at close range. He mentions that in addition to loss of kinetic energy, bullet deformation, and the strength of the medium, bullet accuracy is affected by yaw. Yaw or wobble is longitudinal instability that decreases as the bullet travels further and further down range. DiMaio mentions that yaw can be as great as 2 degrees for a .223 caliber bullet at 70 yards and is the reason that short range wounds cause more damage than long range wounds and that penetration is greater at distance. Yaw may well be the cause for inaccuracy at short range and it is necessary to determine the range at which yaw is small enough to ensure accuracy following glass penetration.

Study Elements Established

The previous research establishes that tempered glass does in fact produce deflection of high and low energy bullets. High energy, soft-point bullets are greatly deformed and fragmented following passage through this medium and are deflected up to five inches at 5 yards. This type of deflection could cause a miss during contingency operations involving glass. Ball ammunition appears to be better suited for glass penetration, and limited tests show that it may not be affected to the degree soft-point ammunition is when penetrating glass. Further testing in this area could provide a table of deflections for an optimum ammunition type. Additional study can be accomplished to determine the minimum stability distance for .308 caliber ball ammunition. The end product might provide information to cover the complete performance profile of .308 ball ammunition and its interaction with tempered glass.

CHAPTER 3

Methodology

Research Design

When conducting contingency operations such as barricaded suspect and hostage incidents, police marksmen frequently encounter 1/4 inch tempered glass as a medium. This medium provides a significant obstacle for marksman who do not know the extent to which bullets are deflected when passing through tempered glass. Previous study and experience has shown that tempered glass can affect bullet trajectory significantly (Albanese, Moody, and Rayi, 1984; Marlow, 1992; and Sanow, 1992). It is necessary to quantify bullet deflection and minimize it in order to provide marksman teams that can guarantee a successful shot in any situation.

Tempered glass is found on every commercial property and supermarket storefront. According to Kingsley Glass of Lancaster, California, 1/4 inch tempered glass is required by building code where glass is within three feet of the ground or any door. Although it is only required by code in these areas, some offices and storefronts are constructed entirely of tempered glass because it costs the same as 1/4 inch pane glass, which is only 1/4 the breaking strength. In addition, many storefronts use smoked glass which can only be manufactured through the tempering process. Kingsley Glass maintains that it is more expensive for storefronts to be divided by tempered and plate glass bordered by metal. It is easier and less expensive to temper the entire front area. Because tempered glass is ubiquitous, and is the strongest of all common storefront glass, it is the subject of this study. Deflection values for 1/4 inch tempered glass should be the

maximum deflection that can be expected for all glass of lesser thickness and lesser strength. Hence, a sniper firing through 1/4 inch plate glass can expect to encounter less deflection than if firing through 1/4 inch tempered glass.

Tempered glass has multiple effects on bullet trajectory. Albanese, Moody, and Rayl (1984) discovered that at close range, bullets that encountered the glass would completely miss the target while when fired at a longer distance to the glass, the bullets were deflected much less. Sanow (1992) discovered that high energy rifle bullets were severely affected by tempered glass, including fragmentation, and were deflected regardless of ra[illegible] fired. Sanow also revealed that high energy soft-point bullets tumbled through the glass, making their ballistic integrity questionable at long ranges following passage through the glass.

This study employs a classic experimental approach combined with action research and development. Data were acquired through direct measurement using experimental apparatus and through mathematical calculation using an experimental mathematical model.

The first phase of the study utilizes a firing range facility and an experimental apparatus in attempt to find the minimum stable firing distance for a 173 grain, .308 cal. rifle round through glass; second, when fired through glass at an angle, a high mass, low deformation bullet (ball ammunition) will be deflected less than a low mass, high deformation bullet such as the soft or hollow-point; and third, while distance is held constant, bullet deflection increases predictably with angle of incidence and these values can be placed into a table for the use of police marksman.

The second phase employs a mathematical model based on Snell's Law using ballistic coefficient, glass density and thickness, bullet mass, and glass angle to predict the deflection of bullets through glass. This model is compared against mean values of deflection in phase one using the Wilcoxon Test to determine the relative accuracy of the data (Blalock, 1960).

Definition and Terms

Ball Round

A full-metal jacketed projectile. The round in this study is the 173 grain lead and antimony slug covered with gilded metal jacket (TC 23-14, 1989,2-26).

Bull Barrel

A rifle barrel that is of uniform thickness from muzzle to breach. The model barrel allows for uniform heating of the barrel throughout its length during firing.

Cold-Barrel Shot

Due to changes in accuracy following heating of a rifle barrel, all shots will be made with a cold barrel. For this study, a cold-barrel shot is one that is taken no earlier than 15 minutes following the previous shot.

Deflection

The horizontal and vertical change in angle of the bullet following passage through the glass. This angle is measured with respect to the angle of incidence. If a bullet has an incident angle of 45 deg. and an exit angle of 35 deg., the deflection is 10 deg. In this experiment, the deflection will be measured by following formula D = InvTan (offset/target distance).

Exit angle

The horizontal angle of the bullet as it exits the glass. A bullet fired at 45 degrees incident angle through glass without a resulting deflection would have an exit angle of 45 degrees

Glass Density

The mass per unit volume of the glass obtained through direct measurement using volumetric displacement and weighing.

Glass/Target Distance

The distance measured from the glass pane to the target surface.

Impact line

The imaginary line drawn from the muzzle of the rifle to the aim point on the target where the bullet would strike if the glass was not present.

Incident Angle

The horizontal angle of the bullet impact on the glass. Fired perpendicular or normal to the glass, the incident angle would be 0 degrees. Fired parallel to the glass surface, the incident angle would be 90 degrees.

Keyhole

The oblong hole that is produced by a bullet that has lost longitudinal stability.

Mean Deflection

The average of the deflection of three cold-barrel shots.

Minimum Stability Distance

The minimum distance where shots fired through a tempered piece of 1/4 inch glass at a 45 degree angle fall within a 5-inch circle on a 5-yard target following deflection.

Muzzle/Glass Distance

The distance measured from the tip of the rifle muzzle to the plane of the glass.

Offset

The horizontal or vertical distance between the bullet impact on the target and the aim point on the target.

Target Distance

The distance measured from the muzzle of the rifle to the target.

Three-Shot Zero

The process of firing three rounds uniformly into the target in order to find the average of the points of impact or the aim point. Each round is fired as a cold barrel shot.

Yaw

Natural longitudinal instability which decreases with range and is imparted to the projectile by the lands and grooves of the barrel rifling

Procedures

Apparatus

Rifle. The rifle is a .308 caliber Remington Police Sniper Special (PSS), serial number C 5637016. A Police Sniper Special is a Remington Model 700 rifle that has a bull-barrel set on a composite, glass bedded stock. The rifle is mounted

with a Leupold VARI-X III 3.5 x 10 power scope. The rifle was sighted in prior to use and bench rested using sand-bags during all firing sequences.

Ammunition. The ammunition for this study is United States Military M-118, .308 caliber, 173 grain, special ball ammunition, lot number LC-87C137-012. This ammunition is extremely accurate and, if fired in a test cradle at 550 meters, will consistently place ten rounds within a twelve-inch circle.

Marksman. The marksman will be the author. The author has qualified as an expert marksman on the United States Army and United States Air Force qualification courses. He has been awarded two Gold Medals and One Bronze Medal during Air Force Command (14 separate bases) and international competition. In order to maintain uniformity, the author will fire all rounds.

Glass. The study used 1x1 ft. sections of 1/4 inch thick commercial tempered glass. The thickness of all of the glass panes was measured using a vernier caliper and found to be of uniform thickness, .2344 inch.

Frame. The frame was constructed with ash wood, .75x1.5x2 foot sections, and encloses the glass pane on all four sides. The base is comprised of horizontal legs that were covered with sand-bags in order to maintain glass position during firing.

Target. The target was a single 1/8 inch-thick silhouette shaped military cardboard target backing with a single sheet of solid white target paper taped over it. The aim point was defined by a right angle drawn with dark brown one-inch thick tape (Appendix H). This aim point method allows the marksman to place the crosshairs of the rifle scope along these lines ensuring exact uniformity in aiming. The target paper is supported by a pine frame.

Plywood. The plywood was placed one yard behind the target paper. This plywood is 5/8 inches thick, 4 ft x 5 ft. common pine, laminated plywood. The plywood was covered with target paper in order to better observe the shape and locations of the rounds once they impacted the wood.

Phase I

Minimum Stability Distance. The purpose of this section of the study is to determine the minimum stable distance that the .308 caliber ball round can be fired at 45 degree angle glass and maintain dispersion within a five-inch circle at 15 yards glass-target distance. The distance was established using a process normally used to adjust mortar rounds. This process is called bracketing. Bracketing guarantees that the minimum stable distance can be reached in five or less iterations and is described below.

Before firing, the target and plywood were placed one yard apart at the end of the 105 meter range. The author used a common builder's level to ensure that both the target and plywood were level and parallel to each other. A table was placed in front of and parallel to the target. The very center of the table was five yards in front of and centered upon the target. The author used tape to mark the center of the table and the 90 degree line for the placement of the glass frame. From the center of this line, the 60 and 45 degree lines were drawn with tape and labeled so that the glass frame could be easily placed at the proper angle with respect to the line of fire. A metal trash can was located on the target side of the table in order to facilitate recovery of the broken glass. This trash can was small enough to fit below the table line and did not interfere with the travel of the glass following firing.

Using a 25 ft. measuring tape, the author measured and staked-off 25 yards, 50 yards, and 100 yards from the center of the table designed to hold the glass frame. All of the distances for the determination of minimum stability distance were measured directly prior to firing.

A second table of identical dimension to the first was used from which to fire the rifle. A tape mark was drawn across the table, three quarters of the way down the table. This line was placed over the distance stake. In addition, the muzzle of the rifle was placed over the end of this tape line in order to ensure it remained exactly on the distance measured. Upon this table were placed two pairs of sand-bags which were used to support the entire forearm of the rifle from the tip of the stock to the very front of the trigger guard. This places all the weight of the rifle on the bags and allows the marksman to minimize vibration and the effects of one's own heartbeat on the aiming of the rifle. Before laying the rifle on the sandbags, the marksman formed a trough in the bags within which the rifle fit. A chair was placed at an angle behind the table to allow the marksman to assume proper foot position, and the butt of the rifle was supported using the non-firing hand which controls elevation by simply squeezing or letting off pressure from the hand.

After being zeroed using several cold barrel shots at 100 yards, three cold barrel rounds were fired through the rifle at two yards muzzle-glass distance in order to establish where the rifle was hitting with respect to the aim point The aim point was adjusted to ensure that the impact line encountered the exact center of the glass when the glass was placed within the frame. A subsequent three-round zero was conducted to ensure the new aim point produced impact through the center of the glass frame. The target penetrations were measured to establish the

grouping of the rounds. Following recording the diameter of the three-shot group on the target and plywood using a vernier caliper, the group was taped over, and the geometric center was marked with a 1/8 inch diameter circle using a felt pen. This was done in order to prevent mistaking a subsequent hole for one of the previous zero holes. This marking was used as the center from which all measurements were made.

The rifle was covered with a towel when not being fired to prevent direct sunlight from increasing the heat of the rifle. In addition, the rifle was cleaned following zeroing and after firing at each set of three glass panes at each position by running one patch containing solvent and two dry patches multiple times through the barrel.

The glass and frame were placed at a 45 degree angle to the line of impact; five yards from the target as measured from the center of the glass pane to the target aim point. Two sand-bags were placed on opposing legs of the frame to prevent movement during firing.

Three successive cold-barrel shots were taken at each position. Following each shot, the marksman recorded the time and noted the temperature using a thermometer located in the shade. The marksman then proceeded to the target and labeled it with pre-printed labels denoting the muzzle-glass distance, glass-target distance, angle, and zero group size and placed a ruler on the target base so that photographs of the target could be examined with a ruler relative to the holes on the target. A black and white photograph was then taken of the target. The target and plywood were then observed to record the impact of the bullet core and jacket relative to the zero mark. The target and plywood were

observed to reveal if the bullets were keyholing and penetrating the plywood. If the target or wood penetration was found to be other than perfectly circular, the dimensions of the hole were measured and recorded. Following measurement the penetration holes were taped over to prevent misinterpretation during subsequent shots.

The three rounds fired at two yards fell well outside of the desired five inch circle of dispersion, so the firing platform was withdrawn to an added distance of four yards for a total of six yards muzzle-glass distance. Had the grouping been less that the desired five-inch dispersion, the platform would have been moved closer to one yard muzzle-glass distance.

The process was again repeated at four and six yards muzzle glass distance and found to be nearly exactly five inches dispersion. The process was repeated again at 10 yards muzzle-glass distance, where all rounds fell within five inches dispersion.

The minimum stability distance will be obtained later in the data analysis section.

Bullet Deflection. The goal of this portion of the study was to plot the mean deflection for the .308 cal. bullet at 25, 50, and 99 yards muzzle-glass distance while the glass was placed at 90, 60, and 45 degrees angle of incidence. In addition, target and plywood penetrations were analyzed to compare relative orientations of the bullet upon penetration in order to establish whether it was tumbling or fragmented.

According to previous protocol, after being zeroed using several cold barrel shots at 100 yards, three cold barrel rounds were fired through the rifle at 25, 50,

and 99 yards muzzle-glass distance in order to establish where the rifle was hitting with respect to the aim point The aim point was adjusted to ensure that the impact line encountered the exact center of the glass when the glass was placed within the frame. A subsequent three round zero was conducted to ensure the new aim point produced impact through the center of the glass frame. The target penetrations were measured to establish the grouping of the rounds. Following recording the diameter of the three-shot group on the target and plywood using a vernier caliper, the group was taped over and the geometric center was marked with a 1/8 inch diameter circle using a felt pen. This was done in order to prevent mistaking subsequent hole for one of the previous zero holes. This marking was used as the center from which all measurements were made.

The rifle was covered with a towel when not being fired to prevent direct sunlight from increasing the heat of the rifle. In addition, the rifle was cleaned following zeroing and after firing at each set of three glass panes at each position by running one patch containing solvent and two dry patches multiple times through the barrel.

The glass and frame were placed at a 90, 60, and 45 degree angle to the line of impact; 5 yards from the target; measured from the center of the glass pane to the target aim point during each respective firing phase. Three shots were measured at 90 degree, then 60 degrees, then 45 degrees. Two sand-bags were placed on opposing legs of the frame to prevent movement during firing.

Three successive cold-barrel shots were taken at each position. Following each shot, the marksman recorded the time and noted the temperature using a thermometer located in the shade. The marksman then proceeded to the target and

labeled it with pre-printed labels denoting the muzzle-glass distance, glass-target distance, angle, and zero group size and placed a ruler on the target base so that photographs of the target could be examined with a ruler relative to the holes on the target. A black and white photograph was then taken of the target. The target and plywood were then observed to record the impact of the bullet core and jacket relative to the zero mark. The target and plywood were observed to reveal if the bullets were keyholing and penetrating the plywood. If the target or wood penetration was found to be other than perfectly circular, the dimensions of the hole were measured and recorded. Following measurement the penetration holes were taped over to prevent misinterpretation during subsequent shots.

The glass and frame were then inspected to determine whether the frame had moved during firing. The glass did not move in any phase of the firing. A new piece of glass was then inserted into the frame and the firing process repeated no earlier than 15 minutes following the previous shot.

A sample piece of glass was obtained from each of the first three panes and placed in a separate bag for a later determination of the density of the glass.

After three rounds are fired at a given angle, the glass and frame were repositioned to the subsequent angle to be measured. The muzzle to glass distance were changed only after all angles for a given set were measured (25, 50, and 99 yards).

Phase II. Mathematical Model

The purpose of this portion of the study will be to utilize the mathematical model developed in the Theoretical Framework section to determine whether it can accurately predict deflection for a given projectile.

Formula. Deflection Angle = INVSIN (TAN i x Δ x T/e^2)

Values. i = Angle of Incidence; Δ = Glass Density x a/m x Cd; T = Glass Thick

Subvalues. a = Bullet Area; m = Bullet Mass; Cd = Ballistic Coefficient

Density Determination. The glass pieces retrieved from the previous phase were used to determine their respective densities using a scale and graduated cylinder. During this procedure, the individual fragments were weighed on a "apothecary" type scale, accurate to .1 gram. Each fragment was then placed individually into a graduated cylinder filled exactly to the 50 ml. mark with water. The initial volume change was noted and water was added using a pipette, that was divided into 1/100 ml. gradations, until the next ml mark was achieved. This added measure of water was subtracted from the overall volume increase in order to determine the volume increase do to the addition of the glass fragment. The density of each fragment was measured to be the mass divided by the volume of displaced water. This procedure was repeated four times to produce a mean density for the glass used in the study.

Glass Thickness. The glass thickness was measured directly for the all panes using a vernier caliper. The mean thickness, .2344 inch., will be used as the thickness in the formula above.

Deflection. Using incident angles of 90, 60, and 45 degrees, and the ballistic coefficient obtained from the manufacturer with the formula above, the deflection angle will be determined for each angle. These values will be place into a table and the results compared with the results from the previous phase using the Wilcoxon Test.

This entire process will be conducted in the data analysis section.

The Instrument

The present study used the tables included in Appendix A-D as instruments for recording observations and the collection of primary data.

CHAPTER 4

Presentation and Analysis of Data

Accuracy of the Study

The Methodology chapter revealed the painstaking efforts taken to maximize control of the shooting environment. All of the procedures were followed methodically and with attention to detail. The most important factor to the integrity of the experiment is the three-shot-zero conducted before firing through the glass at each muzzle-glass distance. The zero not only established the location where the bullets would hit without the presence of the glass; it provided a benchmark for the accuracy of the shots fired subsequently through the glass. A large zero group would naturally mean that the subsequent rounds fired through the glass would experience a wide variation because of the inaccuracy of the marksman alone. However, a tight zero group allows the researcher to assume that all rounds fired through the glass at that distance also hit the glass within the distance established by the zero group.

Table 4.1
Three-Shot-Zero Group Size
(Center to Center Distance)

Muzzle Glass Distance	Zero Group Size
2 yds	.4375 in.
4 yds	.3438 in.
6 yds	.4063 in.
10 yds	.3750 in.
25 yds	.3750 in.
25 yds (Data Left of Normal to Glass)	.3750 in.
50 yds	.6563 in.
99 yds	.6250 in.

Table 4.1 reveals that all of the groups fired are relatively tight groups. Only two of the groups exceed half an inch. To provide an idea of the size of these groups, the largest group (.6563 in.) is only wide enough to span two of the .308 calibre bullets used in this study with just enough room on either side to allow light to pass. For the purpose of this study, these groups are tight enough to effectively rule out the zero group size as the primary cause for the deflection of the bullets fired through glass. It is expected, however, that increased variation in deflection values at greater distance will be a by-product of increased group size.

Minimum Stability Distance

Previous research by Albanese, Moody, and Rayl (1984) suggested that bullets fired close to a 90 degree glass medium produced nearly random deflection on a target placed 60 feet beyond the glass frame. In fact, many of the rounds did not even hit the target.

For the purposes of this study, the minimum stability distance is that distance where bullets fired through 45 degree glass deflect with no more than five inches of dispersion, smaller than the effective diameter of the human head. Figures 4.1-4.4 illustrate the relationship found between distance and dispersion at 45 degrees of glass angle. These figures are reproductions of the target where the zero-zero coordinate is the center of the three-shot-zero group. Figure 4.5 shows the maximum dispersion of the bullet and jacket in the X and Y directions.

Figure 4.1

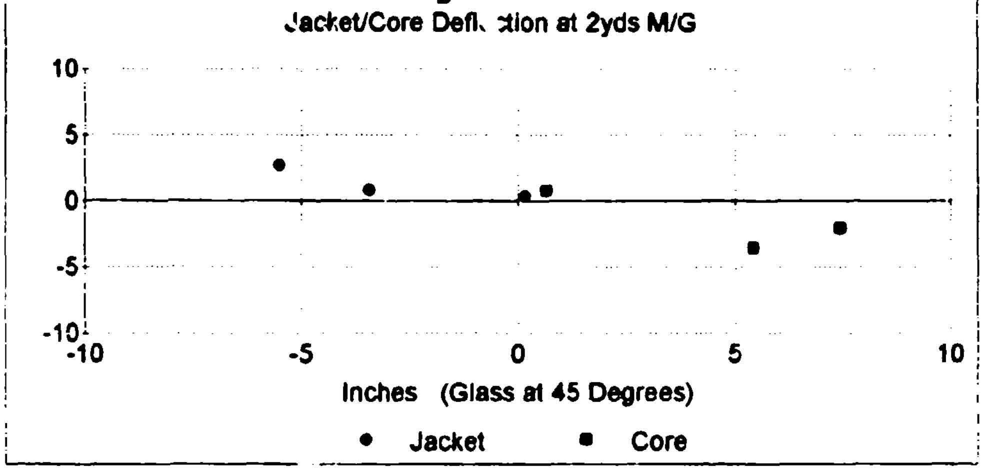


Figure 4.2

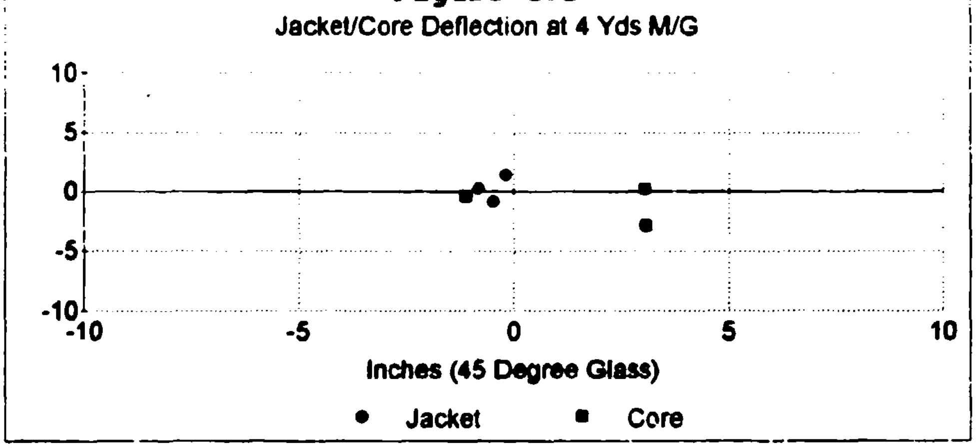


Figure 4.3

Jacket/Core Deflection at 6 yds M/G

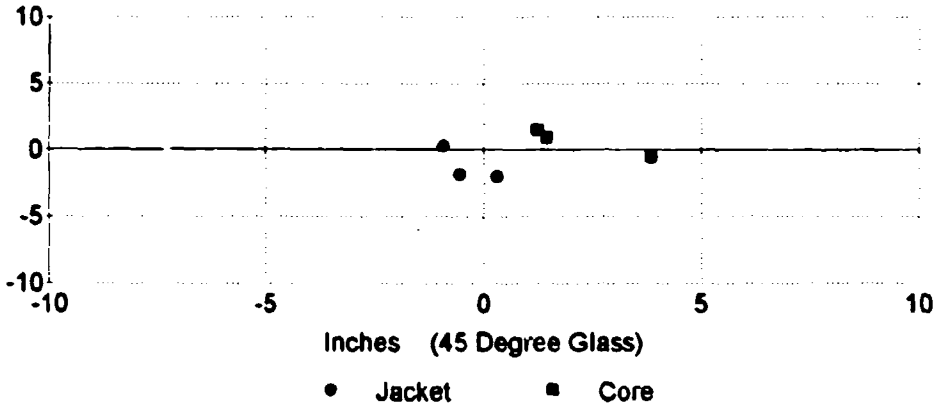


Figure 4.4

Jacket/Core Deflection at 10 yds M/G

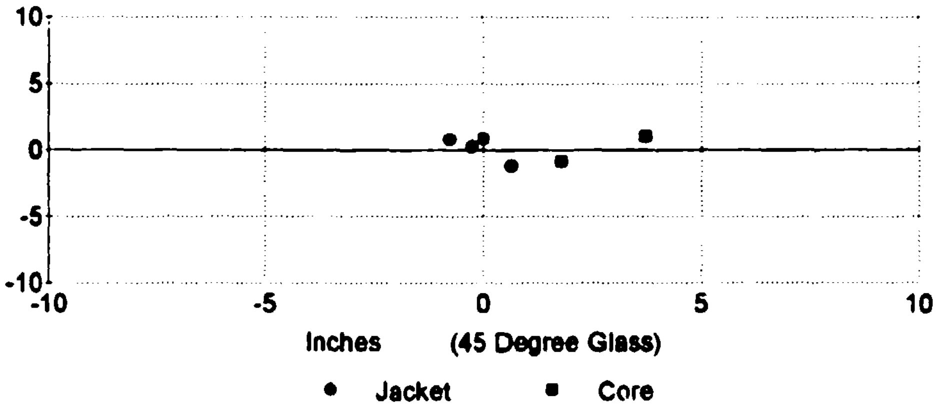
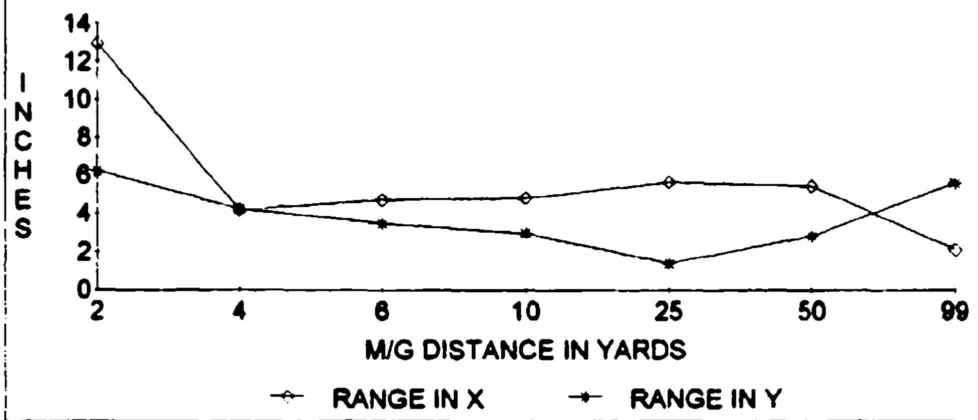


Figure 4.5
Variability of Max X and Y Dispersion



Every round fired at 45 degrees glass angle resulted in separation of the bullet jacket from the core, complicating trajectory and increasing the dispersion of the bullet fragments. The bullets fired at two yards were disbursed over 12 inches in the X direction and over six inches in the Y direction. At four yards, the bullets were dispersed at less than five inches. At six yards, bullets were disbursed almost exactly five inches in the X direction and less than four inches in the Y direction. At 10 through 50 yards, the dispersion remains nearly constant. This establishes that the minimum stability distance lies between two and four yards. There is a possibility that the minimum stability distance lies slightly closer than four yards. However, if one increases the measured variation by the width of the zero group as an error factor, the variation slightly exceeds five inches. Therefore, the minimum ability distance can be effectively located at four yards.

The primary data taken at the range, for the determination of the minimum stability distance, are located in Appendix A.

Bullet Deflection

90 Degrees

The primary data taken for the determination of deflection are located in Appendix A-D. All firing was conducted with the angles measured with the rifle to the right of the normal to the glass. In this manner, physical science dictates that the bullet will deflect to the right. Had the rifle been located to the left of the normal to the glass, the bullets would have been expected to deflect to the left.

Figure 4.6
Bullet Deflection at 25 yds M/G

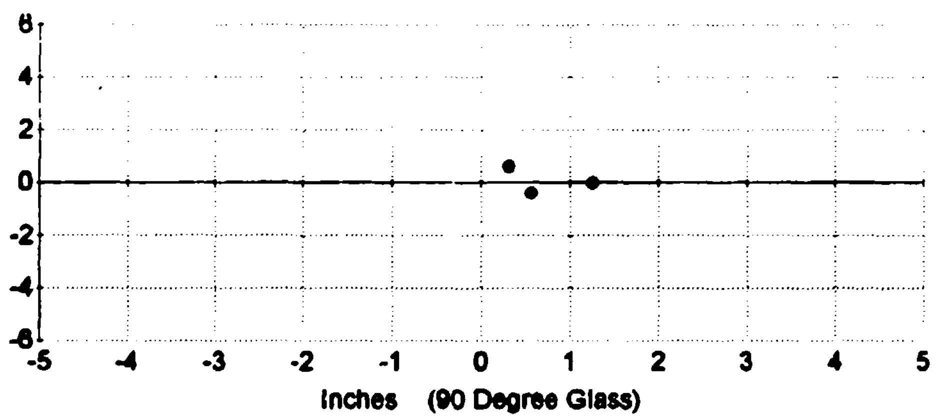


Figure 4.7
Bullet Deflection at 50 yds M/G

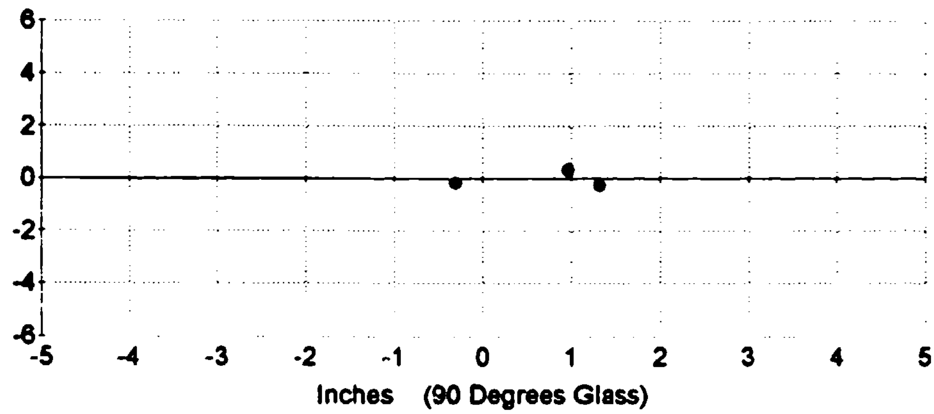
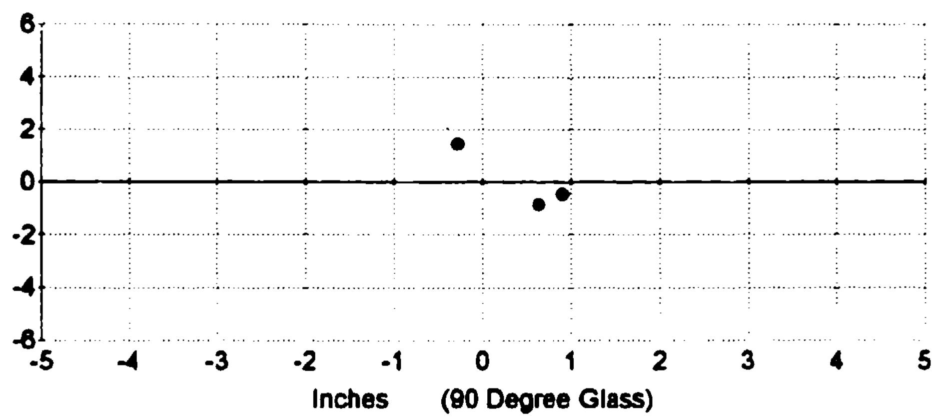


Figure 4.8
Bullet Deflection at 99 yds M/G



Figures 4.6-4.8 show the values taken for deflection at various distances for glass maintained at 90 degrees to the bullet path. These three figures illustrate that bullets are consistently deflected to the right slightly even though the bullet is not experiencing the glass at a deflecting angle. Table 4.2 illustrates that for all distances measured, the bullets deflected to the right within a circle with center at X = .59 and a radius of .9 inch (.59 + .31).

Table 4.2
Mean Deflection of Bullets Fired at 90 Degree Glass Angle (Inches)
(5 yards Glass/Target Distance)

M/G Dist.	Mean X Value	Std. Dev.	Minimum	Maximum
Overall	.59	.60	-.31	1.31
99 yds	.42	.62	-.29	.91
50 yds	.66	.86	-.31	1.31
25 yds	.71	.49	.31	1.25
	Mean Y Value			
Overall	.04	.69	-.84	1.47
99 yds	.06	1.24	-.84	1.47
50 yds	-.02	.32	-.25	.34
25 yds	.08	.51	-.38	.63

The right deflection at 90 degrees might be the result of several factors. All of the bullets in the study appeared to experience tumble after encountering the glass. Some of the bullets entered the targets at a 30 degree angle to the target. That is 60 degrees off of their proper attitude. Another explanation might be deformation. The bullets encountering the glass at 90 degrees were appreciably deformed, some to nearly half their proper length, in a mushroom-like manner. This deformation could have further destroyed the bullet's longitudinal stability and caused it to diverge from its original course. Another plausible explanation might be what aerodynamicists call the Coanda Effect (Chow, 1986, 430-432). The Coanda Effect is increased lift that is created by a round object that is either spinning or encountering fluid motion, such as air. The lands and grooves of the rifle barrel produce a right handed spin of the bullet to give it longitudinal stability. This right-handed (clockwise) spinning action could be compounded by the tumble of the bullet when it hits the glass, pulling it to the right. The Coanda Effect can be a significant force. In fact, Jacques Custeau, the famous scuba diver, utilizes a

ship that is powered by spinning vertical cylinders which create motion when oriented properly to the wind.

Table 4.3
Rate of Change of Deflection
(90 Degree Glass Angle)

M/G Dist. yds	DX Target/yd	DX Wood/yd	Mean (in/yd)
Overall	.118	.103	.110
99	.084	.073	.079
50	.132	.093	.113
25	.142	.147	.144

Computation of the rate of change in the Y direction would have been pointless at 90 degrees since the overall mean change in Y was only .04 inches. However, Table 4.3 provides insight to the rate of increase of deflection of the bullet as it continues down-range after passage through the glass. Deflection is decelerating at roughly .01 inch/yard and is increasing in deflection to the right at .11 inch per yard. This deflection rate is not very generalizable past around ten yards glass-target distance since bullet tumble is likely to cause the bullet to quickly lose all remaining stability.

60 Degrees

The deflection values for 60 degrees angle of incidence (30 degrees to the right of normal) appear in Figures 4.9-4.11. Deflection appears to experience greater variation as distance increases. However, this is partially due to the difference in the "tightness" of the zero groups at these ranges. The zero group at 25 yards is 12/32 inch. while the groups at 50 and 99 yards are 21/32 and 20/32 inch. respectively. As expected, as angle increases, so does the value of deflection.

Figure 4.9

Jac'.et/Core Deflection at 25 yds M/G

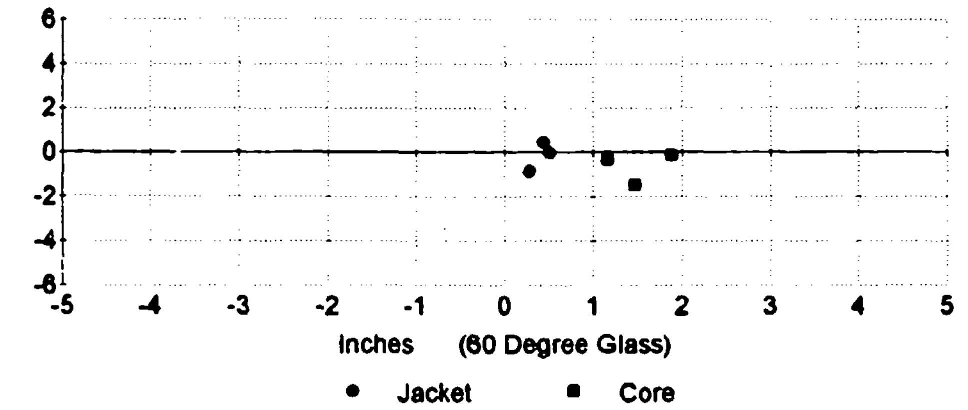


Figure 4.10

Jacket/Core Deflection at 50 yds M/G

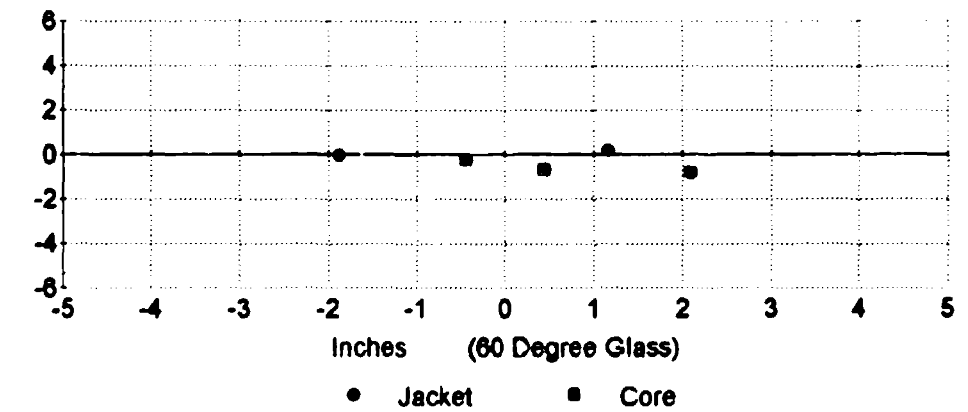


Figure 4.11
Jacket/Core Deflection at 29 yds M/G

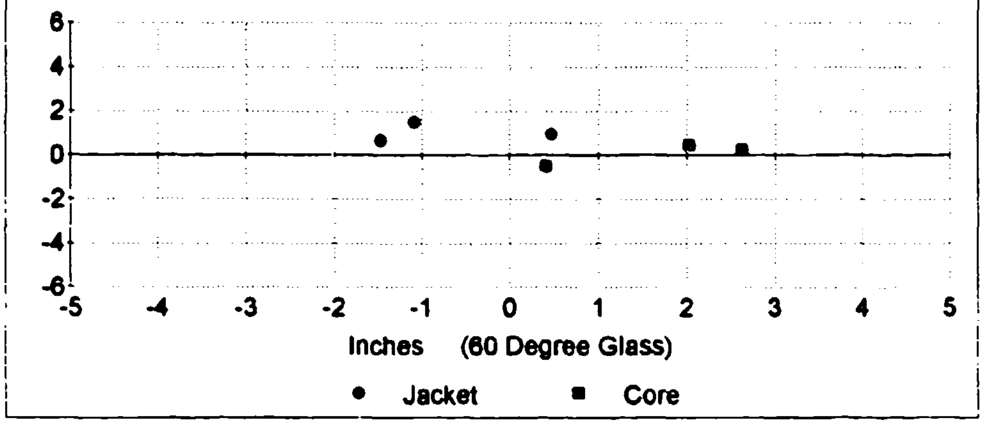


Table 4.4 clearly shows that increasing the glass angle by 30 degrees resulted in shifting the bullet an average of .71 inch further to the right (1.30 inches - .59 inch.). The data taken at 50 yards produced significantly less deflection since one of the bullets did not experience jacket separation and remained intact throughout its passage through the glass as observed in Figure 4.9. In addition, the bullet appears to experience an overall drop in elevation of .37 inch. This drop is not likely associated with the variation in zero groups since it is present to the greatest degree in the data taken at 25 yards where the data had the tightest group.

Table 4.4
Mean Deflection of Core and Jacket Fired at 60 Degree Glass Angle (Inches)
(5 yards Glass/Target Distance)

CORE				
M/G Dist.	Mean X Value	Std. Dev.	Minimum	Maximum
Overall	1.30	.99	-.44	2.63
99 yds	1.69	1.15	.41	2.63
50 yds	.70	1.29	-.44	2.09
25 yds	1.50	.36	1.16	1.88
	Mean Y Value			
Overall	-.37	.57	-1.47	.47
99 yds	.08	.49	-.47	.47
50 yds	-.55	.29	-.78	-.22
25 yds	-.64	.73	-1.47	-.13

JACKET				
M/G Dist.	Mean X Value	Std. Dev.	Minimum	Maximum
Overall	-.23	1.04	-1.88	1.16
99 yds	-.70	1.03	-1.47	.47
50 yds	-.39	1.52	-1.88	1.16
25 yds	.41	.11	.28	.50
	Mean Y Value			
Overall	.31	.70	-.84	1.53
99 yds	1.06	.43	.69	1.53
50 yds	.00	.22	-.22	.22
25 yds	-.13	.67	-.84	.47

A review of Table 4.5 shows the rate of change of deflection for the core and jacket of the bullet as it passes from 5 to 6 yards glass-target distance, the relative distances of the target and the plywood. One may readily observe that the core follows a predictable pattern throughout all of the ranges in that the difference between the overall mean and the mean for the respective ranges is small.

Table 4.5
Rate of Change of Deflection of Core and Jacket
(60 Degree Glass Angle)

CORE			
M/G Dist yds	DX Target/yd	DX Wood/yd	Mean (in/yd)
Overall	.260	.273	.266
99	.338	.318	.328
50	.140	.142	.141
25	.300	.360	.330
	DY Target/yd	DY Wood/yd	
Overall	-.074	-.112	-.093
99	.016	-.067	-.025
50	-.110	-.113	-.112
25	-.128	-.157	-.143

JACKET			
M/G Dist yds	DX Target/yd	DX Wood/yd	Mean (in/yd)
Overall	-.046	-.008	-.027
99	-.140	-.035	-.088
50	-.078	-.082	-.080
25	.082	.090	.086
	DY Target/yd	DY Wood/yd	
Overall	.062	.027	.044
99	.212	.163	.188
50	-.078	-.043	-.061
25	-.026	-.038	-.032

However, the jacket deflection rate is almost entirely random. This relation will also be observed in the next section for the 45 degree data. The reason for this randomness must be due to the relative mass of the jacket compared with the core. According to Luann Bennett of Olin-Winchester Corporation's International Marketing Branch, the jacket comprises only 60 grains of the total 173 grain bullet

or slightly over one third of the bullet mass. In addition, when separated from the core, the jacket is aerodynamically similar to a cup with a small moment of inertia compared with the core and is subject to the effects of drag and increased loss of momentum. All of these variations create a fragment which decreases the overall predictability of bullets fired through glass. Finally, this variation increases the size of the expanding circle of lethal fragments following the passage of the bullet through the glass. At 90 degrees, the bullets remained intact, creating an expanding circle of fragments of diameter 2.31 inches while the multiple fragments at 60 degrees created an expanding circle of 4.51 inches in diameter.

45 Degrees

Regardless of initial group size at each respective distance, the dispersion of bullets at 45 degrees is great. Figures 4.12-4.14 show that the rounds experienced average dispersions of over 2 inches for the core alone.

Figure 4.12

Jacket/Core Deflection at 25 yds M/G

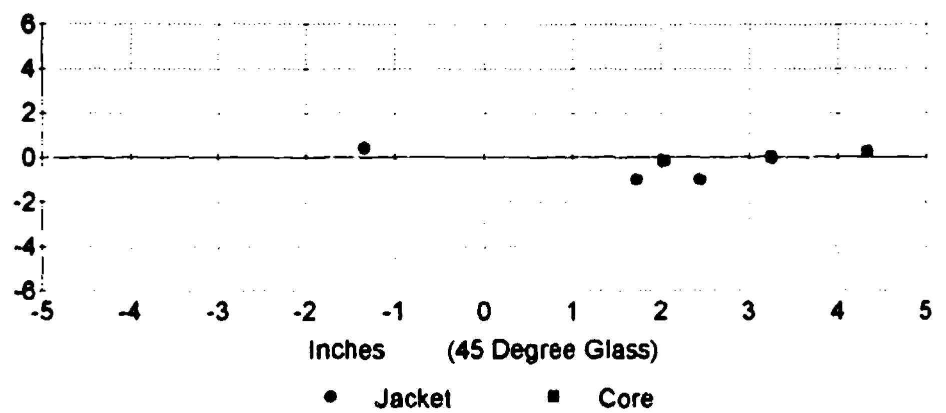


Figure 4.13

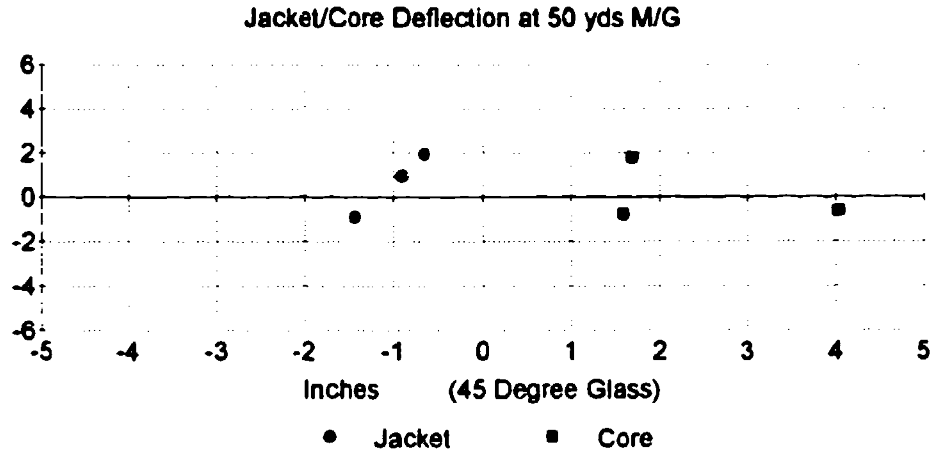


Figure 4.14

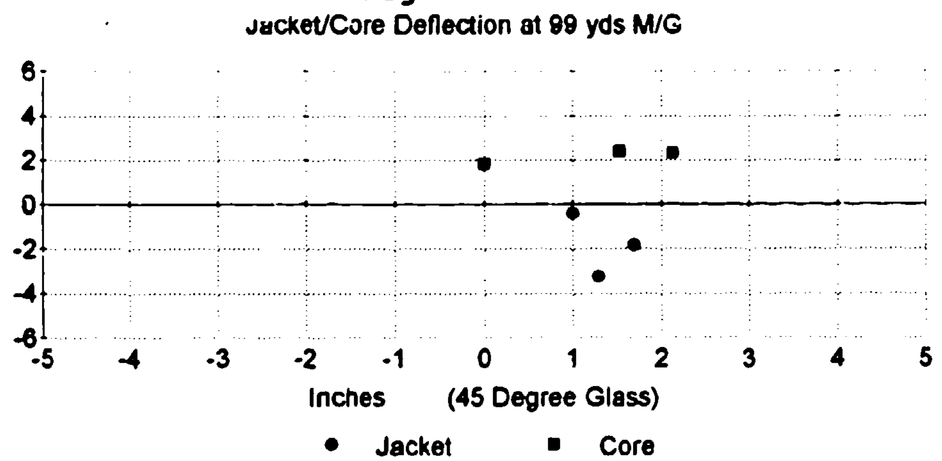


Table 4.6
Mean Deflection of Core and Jacket Fired at 45 Degree Glass Angle (Inches)
(5 yards Glass/Target Distance)

CORE				
M/G Dist.	Mean X Value	Std. Dev.	Minimum	Maximum
Overall	2.17	1.42	.00	4.34
99 yds	1.22	1.10	.00	2.13
50 yds	2.44	1.38	1.59	4.03
25 yds	3.21	1.16	2.03	4.34
10 yds	1.83	1.86	.00	3.72
	Mean Y Value			
Overall	.70	1.20	-.78	2.41
99 yds	2.20	.31	1.84	2.41
50 yds	.16	1.44	-.75	1.81
25 yds	.03	.20	-.16	.25
10 yds	.40	1.02	-.78	1.06

JACKET				
M/G Dist.	Mean X Value	Std. Dev.	Minimum	Maximum
Overall	.28	1.34	-1.44	2.44
99 yds	1.32	.35	1.00	1.69
50 yds	-1.00	.40	-1.44	-.66
25 yds	.94	2.01	-1.34	2.44
10 yds	-.15	.71	-.78	.63
	Mean Y Value			
Overall	-.40	1.40	-3.22	1.97
99 yds	-1.80	1.42	-3.22	-.38
50 yds	.69	1.44	-.88	1.97
25 yds	-.50	.81	-.97	.44
10 yds	.03	1.04	-1.13	.88

As angle increased, so did the standard deviation of the bullets from the mean in the X direction: from an average of .60 inch at 90 degrees to .99 inch at 60 degrees to 1.42 inches at 45 degrees. It is possible that variation is related to angle of incidence.

Table 4.7
Rate of Change of Deflection of Core and Jacket
(45 Degree Glass Angle)

CORE			
M/G Dist yds	DX Target/yd	DX Wood/yd	Mean (in/yd)
Overall	.434	.465	.450
99	.244	.275	.260
50	.488	.472	.480
25	.642	.708	.675
10	.366	.403	.384
	DY Target/yd	DY Wood/yd	
Overall	.140	.178	.106
99	.440	.452	.446
50	.032	.208	.120
25	.006	-.030	-.012
10	.080	.083	.082

JACKET			
M/G Dist yds	DX Target/yd	DX Wood/yd	Mean (in/yd)
Overall	.056	.076	.066
99	.264	.256	.260
50	-.200	-.053	-.127
25	.188	.112	.150
10	-.030	-.008	-.019
	DY Target/yd	DY Wood/yd	
Overall	-.080	-.100	-.090
99	-.360	-.315	-.338
50	.138	.098	.118
25	-.100	-.150	-.125
10	.006	-.038	-.016

Table 4.6 provides that deflection has again increased further to the right at 45 degrees to a mean X deflection of the core of 2.17 inches. Overall dispersion of the fragments has not changed significantly from 60 degrees to 45 degrees. All of the fragments remain in a roughly five-inch diameter circle.

Tables 4.6 and 4.7 illustrate how the jacket is again highly variable at 60 degrees while the core remains predictable and located closer to the mean.

Center of Mass

The previous data provides that when separation of the bullet and jacket occur, the core experiences less variability when compared with the jacket. One of initial premise of the present study was to determine whether the .308 cal. ball round would fragment upon impact with the glass. This fact is now readily apparent. At 90 degrees, the bullet experiences significant deformation, yet no jacket separation. However, when the bullet encounters the glass at an angle, the bullet jacket will separate from the core, nearly doubling the overall dispersion of lethal fragments in the target area.

Another problem, which resulted from jacket separation, is the increased variability of the rounds once separation occurred. This fact calls into question the accuracy of the initial zero rounds compared with the subsequent glass penetration rounds. Were they actually impacting the glass at the center, and were they actually being aimed as carefully as those rounds previously used for the three-shot-zero? An initial answer may come from the overall accuracy of the rounds fired at 90 degrees. Their overall accuracy may be found in the fact that all fell within a mean dispersion of .59 inch in the X direction and .04 in the Y direction with a standard deviation of .60 and .69 inch respectively. However, the subsequent rounds, fired at angles, had significantly higher standard deviations.

Accuracy for the subsequent rounds may be assessed by determining where those rounds would have impacted the target had they not experienced jacket separation. This point of impact is discernible in the same manner one would

determine the point of origin of an explosion, or the way a scientist might determine the origin of an exploding supernova. By determining the location of the relative fragments and their masses, one may determine the center of mass of the bullet. Previously, the researcher established that the projectile weight included a 60 grain copper jacket and a 113 grain core to comprise a 173 grain bullet. Using their relative weights, one may reason that the jacket is 34.68% of the total weight and the core is 65.32%. By multiplying the percentage by the relative X or Y distance, summing the total and dividing by 100 %, one will achieve the location of the X and Y center of mass:

X Center of Mass = (XCore x 65.32 + XJacket x 34.68)/100

Y Center of Mass = (YCore x 65.32 + YJacket x 34.68)/100

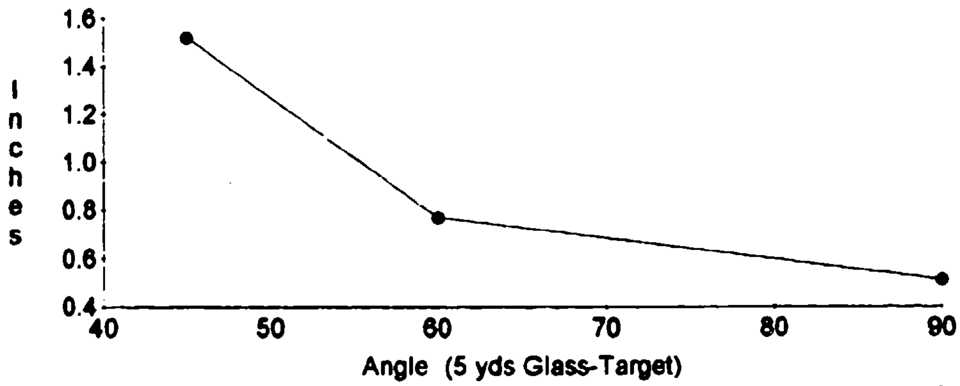
Table 4 8
Location of the Center of Mass
(5 yards Glass/Target Distance)

Angle	M/G Dist.	Mean X Value	Std. Dev.	Minimum	Maximum
90	Overall	.59	.60	-.31	1.34
60	Overall	.77	.76	-.44	1.77
45	Overall	1.52	.98	-.27	2.97
		Mean Y Value			
90	Overall	.04	.69	-.84	1.47
60	Overall	-.13	.50	-.80	.84
45	Overall	.32	.57	-.44	1.40

Table 4.8 provides the location of the center of mass for all rounds fired at their respective angles. This impact point is also the location of the impact had the jacket not separated from the core. One may see that the X deflection increases predictably with increased angle and the Y appears to center around the zero point. Figure 4.15 also provides the relation between glass angle and x deflection of the center of mass at target impact.

Figure 4.15

X Location of Center of Mass



Correlation

The data collected for the study have been presented in Figures 4.1-4.15 and observation of this data reveal that it is normal data located about an X and Y mean. As ratio level data, the relations for this study are subject to interpretation using Pearson's Product Moment Correlation or (r). Using the software readily available from *SPSS/PC+ Studentware Plus*, the researcher conducted a correlation of angle, distance, and deflection in order to determine the effects of each on deflection of the bullet.

Table 4.9
Correlation

Variable	M/G Distance	Angle
M/G Distance	1.0000	.1418
Angle	.1418	1.0000
Target XCore	-.2279	-.5170*
Wood XCore	-.2701	-.5494**
Target XJacket	-.0045	.1501
Wood XJacket	.0691	.0855

* = .05 **= .001 Level of Significance

Table 4.9 illustrates that 100 yards muzzle-glass distance is insignificantly related with angle and that the deflection increases significantly as the angle of incidence to the glass decreases. In addition, the instability of the jacket is also revealed by its position and there is no significant relation with either distance or angle.

Since distance up to 100 yds does not affect the value of deflection of bullets through 1/4 inch tempered glass, the overall values of deflection found for each angle can be generalized to represent the deflection values for the entire range from four yds to 100 yds (Figures 4.16-4.18).

Table 4.10
Overall Deflection Over a 4-100 Yard Interval M/G
(M-118 Special Ball .308 (7.62mm) 173 grains, Full Metal Jacket)

Angle	Deflection (in.)	Max Dispersion	Fragments
90	right .59	2.94 in. dia. circle	1
60 right	right 1.30	6.36 in. dia circle	1-2
45 right	right 2.17	7.22 in dia. circle	2
(right of normal to glass)		(max area for projectiles)	

Figure 4.16
Jacket/Core Deflection at 45 Deg Right

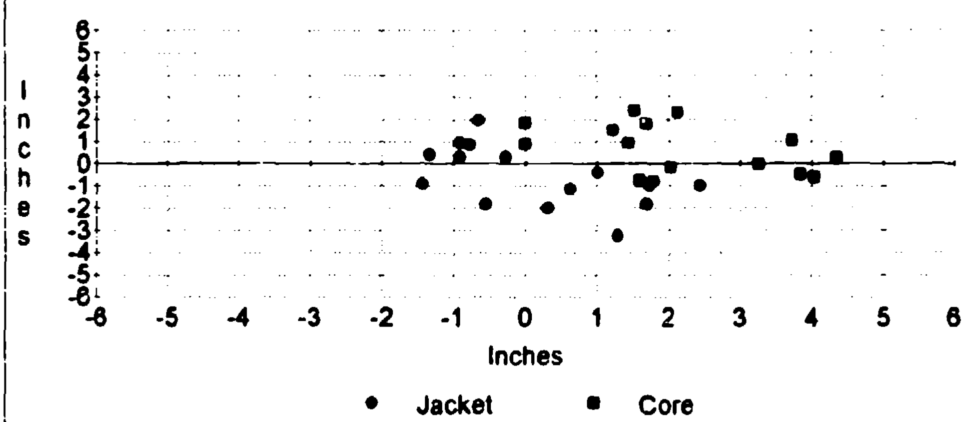


Figure 4.17
Jacket/Core Deflection at 60 Deg. Right

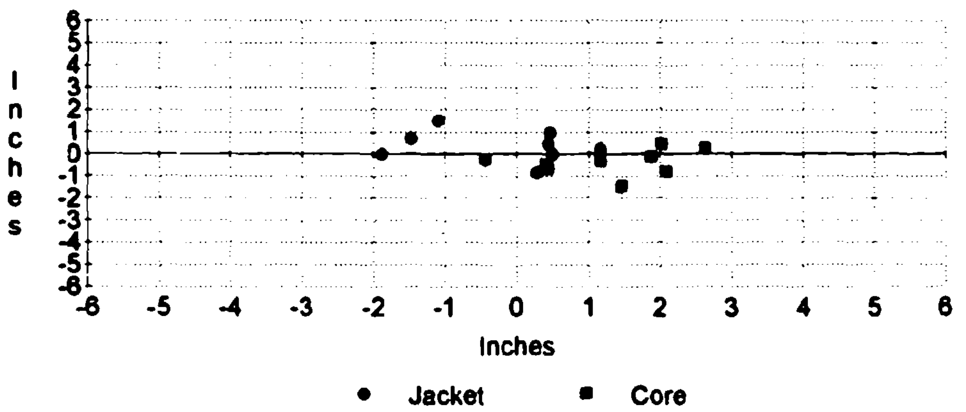
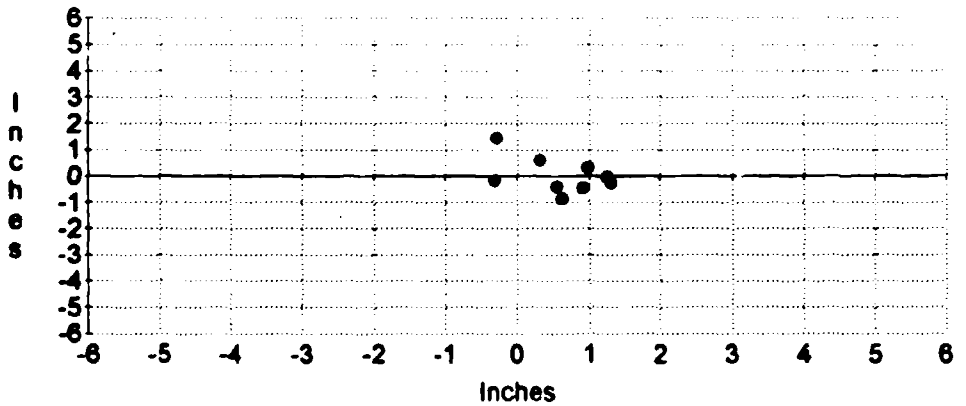


Figure 4.18
Bullet Deflection at 90 Degrees



Mathematical Model

Using the procedure defined in the methodology chapter, density was measured for a total of four glass fragments and averaged in order to determine the glass density to be used for the experiment. Table 4.11 shows the means density to be .088 lb/cu.in.

Table 4.11
Measured Density of Glass Fragments
(1/4 in. Tempered Glass)

Fragment	Density(g/cu.cm.)	Deviation from Mean
1	2.490	+.051
2	2.427	-.012
3	2.442	+.003
4	2.397	-.042

Mean Density = 2.439 g/cu.cm. = .088 lb/cu.in. Standard Dev = .027 g/cu.cm.

Table 4.12
Mathematical Deflection Determination

Incident Angle	Deflection Angle	*Deflection (in.)
0 degrees (90 deg. glass angle)	0 degrees	0.000
30 degrees (60 deg. glass angle)	.12326	.387
45 degrees (45 deg. glass angle)	.21359	.671

*Deflection given for 5 yd (180 in.) glass-target distance

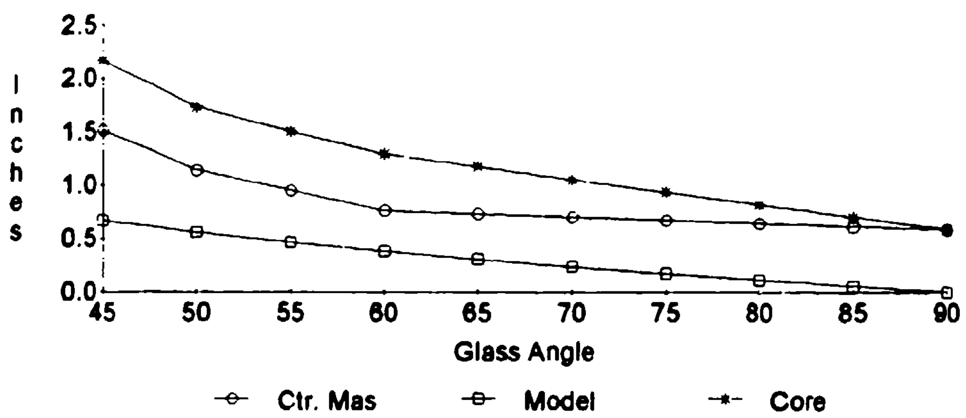
a = 3.14159 x r^2 = 3.14159 x (caliber of bullet/2)^2 = .0745 sq.in.
Cd = .443 (From Olin-Winchester Cartridge Corp.)
m = 173 grains x 1lb/7000 grains = .024714 lb.
Density = .088 lb/cu.in.
Δ = Density x a/m x Cd = .1175167
T = .2344 in.
e^2 = 7.389056
Deflection Angle = INVSIN (TAN i x Δ x T/e^2)
Deflection Angle = INVSIN (TAN i x .0037279)
TAN(Deflection Angle) = Deflection/180 inches Where 180 inches = 5 yds.
Deflection = TAN (Deflection Angle) x 180 inches

Table 4.12 illustrates the calculated values for deflection for a glass-target distance of five yds. One can readily observe that these values do not exactly correspond to the values obtained for 90, 60, and 45 degrees glass angle by direct

measurement (.59,1.30,2.17), or by center of mass determination (.59, .77, 1.52). In this respect, any attempt to conduct a statistical test to determine whether the model is similar to the measured deflection would be futile. However, the mathematical model may have a degree of validity that cannot be determined with the present data or bullet. The measured mean deflections and the center of mass deflections are for a bullet that has deformed appreciably at every angle. In addition, with the addition of any incidence angle, the bullet is stripped of its jacket; compounding the effects of deflection produced by the glass alone. One might expect that deformation would add to the values of deflection. This is consistent with the measured data and the center of mass data. In the previous section, the center of mass deflection was determined to be the point where the bullet would have impacted had it not experienced jacket/core separation. This point is where the deformed but intact bullet would have landed. It might be possible that an undeformed bullet would have landed even closer to the zero, within the deflections predicted by the mathematical model.

Figure 4.19

Comparison of Deflections



The present mathematical model does not accurately predict deflections for bullets that deform when encountering glass. Figure 4.19 shows how the mathematical model predicts less deflection than actually occurs when the bullet deforms. However, the slope appears to be relatively similar at glass angles between 60 and 90 degrees. It appears if the origin for the mathematical model were shifted by adding .59 (the 90 degree deflection for the center of mass) to the deflection values, the deflections would more accurately depict the true deflection. By shifting the model by adding .59 to each value, the measured deflections are off by only 0.0, .207 and .254 inch for 90, 60, and 45 degrees respectively. In this manner, the predicted values of the mathematical model more closely approximate the measured values of deflection. In order to conduct a Wilcoxon test deflections were calculated for 90 to 45 degrees glass angle, in five degree intervals, for the mathematical model and the measured data. The measured data points were plotted by calculating points along the slopes of the lines between 90-60, and 60 45 degrees glass angle respectively. Table 4.13 shows that the unadjusted model falls 2.8 standard deviations from the standardized mean while the adjusted model falls within 1.6 standard deviations with a low probability of .0051 and .1097 respectively. For the adjusted model, the null hypothesis that there is no significant difference between the adjusted mathematical model and the measured values of deflections must be retained because the significance is greater than .05.

Table 4.13
Wilcoxon Test Results

Models Compared	Z Score	2 Tailed P
Center of Mass with Mathematical Model	-2.8031	.0051
Center of Mass with Adjusted Model	-1.5993	.1097

For bullets that deform on impact with the glass, the mathematical model must be modified as follows:

Deflection Angle = INVSIN (TAN i x Δ x T/e^2) + *(90 deg. Deflection Angle)
*Measured by actual test

This method is still inaccurate since the bullet's energy is further changed by the deformation and loss of mass when penetrating glass.

It is apparent that further experimentation is necessary to be able to predict the deflection of a bullet by mathematical model alone.

CHAPTER 5

Conclusions

Discussion

Bullet Performance

At the outset, one of the intentions of this experiment was to determine qualitatively whether a fully jacketed bullet would perform better than a round-nose or hollow-point bullet. Initial assumptions were that the jacketed bullet would remain intact throughout the range of glass angles. This, however, was not the case. When the bullets impacted the glass, the tip was severed from the round. This tip, comprised of the jacket tip and small lead fragments, continued along the surface of the glass until the tip particles impacted with the left portion of the test frame. This separation aided in the determination that the bullet was impacting the geometric center of the glass since the fragments from the 36 rounds fired created a crater in the center of the left side of the frame. As the bullet continued through the glass, the remaining nose portion mushroomed back. For those bullets impacting the glass at an angle, the force of impact peeled the jacket away; leaving a lead core, and a parachute-like piece of copper jacket to continue as two separate lethal fragments. In all cases, the bullets experienced tumble due to loss of stability.

The jacketed bullet did perform slightly better than the round-nose and soft-point bullets. Sanow (1992) determined that soft-point ammunition consistently deflected between .67 inch at 90 degrees, and 2.5 inches at 45 degrees at 5 yards glass-target distance. The fully jacketed ammunition deflected .59 and 2.17 inches at 90 and 45 degrees respectively at five yards glass-target distance. This

difference is only slight and not enough to discard the null hypothesis that there is no difference between the round-nose and fully jacketed deflection of bullets. However, the deflections for the Sanow study were obtained for 1/4 inch plate glass, which has only 1/4 the breaking strength of tempered glass of the same thickness (Kingsley Glass, 1994). Given this, it would be safe to generalize that a fully jacketed bullet is certain to perform within the measured values for this study for both 1/4 inch pane and tempered glass.

Stability Distance

This study revealed that the .308 cal. bullet is unstable for shots made under four yards muzzle-glass distance through 45 degree glass. Shots made within four yards distance will result in dispersion of lethal fragments in a circle over four inches in diameter at five yards.

Beyond four yards, muzzle-glass distance, the .308 cal. bullet is stable and produces consistent and predictable groups under five inches in diameter at five yards glass-target distance. Beyond four yards, muzzle-glass distance, the bullet is predictable throughout all angles of the glass between 45 degrees and 90 degrees.

Bullet Deflection

This study determined that distances between four and 100 yards have no measurable effect on the deflection of .308 cal. bullets, however, glass angle and deformation do affect deflection.

Deflection at 90 degree glass angle consistently produces a slight right deflection of the bullet. This fact is also confirmed by the data in Rios' study (1990, 85) where bullets fired through metal plate also consistently deflected to the right at 90 degrees (measured as 0 degrees in his study). Since the bullet tends to

deflect to the right at 90 degrees, bullet deflection measured for impacts to the right of normal should be greater than bullet deflections for impacts to the left of the normal to the glass. In essence, the 90 degree deflection value should be the new zero point. In this manner, a marksman firing into the glass at 45 degrees to the right of normal would experience a mean deflection of the core of 2.17 inches to the right or 1.58 inches to the right of the 90 degree deflection mark. A marksman firing to the left of the normal to the glass should experience a deflection of -.99 inch or 1.58 inches to the left of the 90 degree deflection value. This, however, is not the case. The author conducted a limited test by firing at six glass panes, 3 at 60 degrees and 3 at 45 degrees left glass angle. These shots were conducted at 25 yds muzzle-glass distance using the same procedure explained in Chapter 3. The targets are reproduced as Figures 5.1-5.2 from the data enclosed as Appendix I. These figures illustrate that data taken from shots placed left of the normal to the glass are highly variable, unlike the data taken from the right side of the normal to the glass. In addition, the core of the bullets consistently deflect to the right rather than to the left with a mean deflection of the core of .70 inch. at 45 degrees left, and -.09 inch at 60 degrees left. Figure 5.2 shows that the core also drops an average of 1.78 inches after penetrating the glass.

Figure 5.1

Jacket/Core Deflection at 25 yds M/G

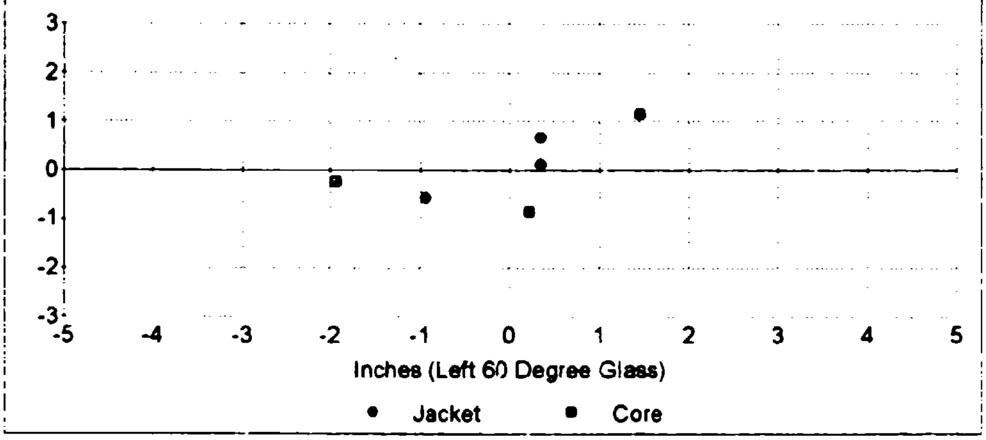
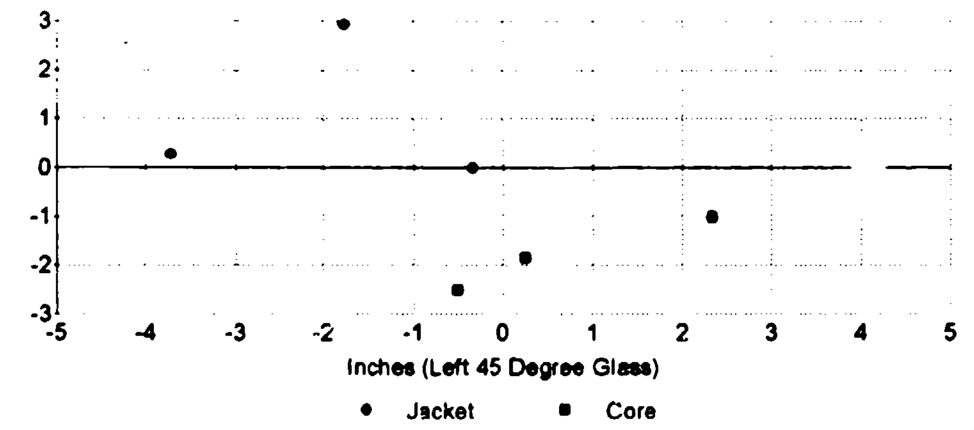


Figure 5.2

Jacket/Core Deflection at 25 yds M/G



It is surprising to note that the center of mass of the bullet fragments, however, consistently deflect to the left of normal as physics dictates. Table 5.1 shows that although the core is deflecting toward the right, the jacket deflection is even more rapidly increasing toward the left, thereby continuing the steady progression of the center of mass to the left.

Table 5.1
Location of the Center of Mass
(5 yards Glass/Target Distance)

Angle	M/G Dist.	Mean X Value	Std. Dev.	Minimum	Maximum
-60	25 yds	-.09	.93	-1.15	.61
-45	25 yds	-.22	.63	-.94	.24
		Mean Y Value			
-60	25 yds	.05	.53	-.50	.56
-45	25 yds	-.79	.36	-1.20	-.56

It appears that shots made left of the normal to the glass result in huge dispersions of the jacket and core. These dispersions could be a result of the right-handed spin of the bullet. The spinning bullet behaves as a gyroscope with its momentum vector pointing up through the nose of the bullet. This momentum vector is dictated by the spin. A spinning bullet follows the "Right Hand Rule" (Zafiratos, 1985, p 180) where an object spinning to the right dictates an upward momentum vector. The momentum is about the bullet's center of mass, located behind the bullet tip. When the bullet tip encounters the glass, it produces a moment about the center of mass of the bullet which can alter the original momentum vector. This torque can cause the bullet to precess (p197) or oscillate about the original momentum vector. This precession, could allow the bullet to experience the Coanda Efect which could be what pulls the bullet core toward the right regardless of the effect of the glass. The jacket of the bullet quickly looses its spin and continues opposite the path of the core. Table 5.2 provides a means to predict deflection using the data for the present study.

Table 5.2
Deflection
(4-100 yds Muzzle Glass Distance)

Glass Angle Degrees	Lethal Circle Max Size Inches	Glass Tgt Dist Yards	Deflection Core (In.)	Fragment Number
-45	9	5	.70	2
		2.5	.35	2
-60	6	5	-.09	2
		2.5	-.05	2
90	2.94	5	.59	1
		2.5	.30	1
60	6.36	5	1.30	2
		2.5	.95	2
45	7.22	5	2.17	2
		2.5	1.38	2

Mathematical Model

Rios (1990) determined that bullet deflection through steel plate did not perform in a simple linear relationship based on velocity change and angle alone. It also depends upon factors such as thickness of the medium, ballistic coefficient, and density of the medium. In the present experiment, these factors were tak·n into account. However, until the effect of bullet deformation and jacket separation can be predicted, mathematical interpretation is futile.

One premise of this experiment was that the full metal jacketed bullet would experience little deformation, compared with the deformation experienced with soft-pointed bullets. It was assumed that the separation of the jacket in soft pointed bullets was due to the exposure of the jacket in th- --se when penetrating the glass, making it more susceptible to jacket separation. However, the pointed

nose of the jacketed round actually broke off during glass impact, creating a bullet that behaved similar to a soft-pointed bullet.

Implications

Deflection

The data gathered in this experiment, especially Table 5.2, may be used by marksman teams to predict the deflection of full-metal-jacketed shots placed through glass 1/4 in. thick. However, these deflection values should be considered maximum values for glasses of lesser thickness or 1/4 in. plate glass since these glasses are less strong and produce less overall energy loss of the bullet. Since deflection was found not to be related to muzzle-glass distance for bullets fired between 4 yds and 100 yds, Table 5.2 is accurate for all ranges between 4 and 100 yds.

Shots placed to the left of the normal to the glass produce greater variation in dispersion of the core and jacket. Marksman should be cautioned that fragments appear highly variable and the lethal circle of dispersion mentioned in Table 5.2 for these values should be considered the minimum values until further research into shots fired left of center can be conducted.

Shots placed at 90 degrees glass angle are very reliable. During this experiment, the bullet remained intact for all rounds fired at 90 degrees; making the spread of lethal fragments a small circle. If a marksman had to make a shot where the available target area is small, a 90 degree shot would result in an accurate and predictable impact. A preliminary shot to eliminate the glass would not be necessary. The author would caution, however, that the marksman must know the trajectory of the first cold barrel shot to ensure the bullet impacts at 90

degrees. The rifle used in this experiment typically shot high for the very first shot of the day while the subsequent shots, separated by a 15 minute interval, were on target. The marksman must adjust for the very first cold barrel shot to ensure the error of the first cold barrel shot does not produce an incident angle. This can be done by consistently logging the position of the first cold barrel shot.

The marksman must be aware that bullets that deform on impact with the glass also create a circle of dispersion. This circle is given in Table 5.2. when making a shot, this is the minimum area that must be secured in order to prevent a hostage from being hit by a lethal fragment.

During the shooting phase of the present experiment, the researcher noted that glass fragments penetrated the initial target and impacted the wood. None of these fragments penetrated the wood farther than approximately 1/4 of the 5/8 in. thickness. These fragments are of concern. They are not lethal in nature; however, they could cut an artery or blind a hostage near the impact zone. This is a risk; however, the noticeable fragments remained close to the impact zone of the bullet.

Prediction

The mathematical model used in this experiment is not applicable for bullets that experience break-up or significant deformation on impact. It may be applicable for bullets that do not deform on impact with glass.

The use of armor-piercing bullets for shots through glass would be dangerous in an urban setting where there is a danger of over-penetration. These bullets are commonly constructed of depleted uranium, steel, or other metal substances that would continue through flesh, concrete, and armor plate. However, if one were to

develop a bullet that could withstand the force of impact of glass, yet deform on impact with concrete or other common building materials, one would have a very good bullet for use by marksman teams. There are Teflon-coated bullets being manufactured today. These bullets are not as durable as armor-piercing bullets; however, they are considerably stronger than jacketed bullets. One such round is manufactured for the .375 cal. H-H Magnum for use against Elephants and Kodiak Bear. A similar round in .308 cal. could prove to be an expensive, yet worthy, element of study.

Recommendations for Future Research

Future research is necessary in the following areas:

1. Deflection could be measured for shots placed to the left of 90 degrees glass angle in order to determine whether the determinations in Table 5.2 are fully accurate.

2. Further experimentation is necessary to find a bullet that will not deform or fragment upon impact with the glass. Initial shots could be tested at 45 degrees glass angle; beyond the 4 yd minimum stability distance; with three panes of glass for each test bullet.

3. Once a bullet that does not deform significantly on impact is found, further testing can be done to determine the accuracy of the mathematical model used in the present experiment.

4. If a non-deforming bullet is not found, further research should be done to plot deformation and attempt to fit it with the mathematical model used in the present experiment.

5. Research should be conducted to determine the effect of spin on bullet deflection. this research should be performed using close range shots through identical rifles with right hand twist, left hand twist, and no twist rifle barrels.

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SHOT	MUZZLE TO GLASS DISTANCE	GLASS ANGLE	FRAGMENT	INCHES OF TARGET X DEFLECT	INCHES OF TARGET Y DEFLECT	INCHES OF PLYWOOD X DEFLECT	INCHES OF PLYWOOD Y DEFLECT	DEGREES TARGET TUMBLE	DEGREES PLYWOOD TUMBLE
1	2 yds	45	JACKET	-3.44	0.88	-3.44	1.13	30.92	0.00
			CORE	7.44	-2.00	9.38	-2.13	21.07	0.00
2	2 yds	45	JACKET	0.16	0.44	0.53	0.44	0.00	0.00
			CORE	0.66	0.81	0.91	0.91	49.63	0.00
3	2 yds	45	JACKET	-5.50	2.75	-6.25	3.50	18.55	15.71
			CORE	5.44	-3.50	7.40	-3.50	31.76	28.44
1	6 yds	45	JACKET	0.31	-1.97	0.56	-1.63	72.39	0.00
			CORE	1.44	0.94	1.88	1.27	0.00	0.00
2	6 yds	45	JACKET	-0.56	-1.81	-0.31	-2.06	10.87	0.00
			CORE	3.84	-0.47	4.69	-0.63	0.00	0.00
3	6 yds	45	JACKET	-0.91	0.34	-0.97	0.38	0.00	17.71
			CORE	1.22	1.53	1.56	2.44	33.37	33.75
1	10 yds	45	JACKET	-0.28	0.34	-0.31	0.21	0.00	33.75
			CORE	1.78	-0.78	2.84	-0.69	31.76	28.07
2	10 yds	45	JACKET	-0.78	0.88	-1.28	1.03	0.00	0.00
			CORE	0.00	0.91	-0.16	1.22	0.00	31.97
3	10 yds	45	JACKET	0.63	-1.13	1.44	-1.94	0.00	0.00
			CORE	3.72	1.06	4.56	0.97	0.00	41.81

APPENDIX A. MINIMUM STABILITY DATA

SHOT	MUZZLE TO GLASS DISTANCE	GLASS ANGLE	FRAGMENT	INCHES OF TARGET X DEFLECT	INCHES OF TARGET Y DEFLECT	INCHES OF PLYWOOD X DEFLECT	INCHES OF PLYWOOD Y DEFLECT	DEGREES TARGET TUMBLE	DEGREES PLYWOOD TUMBLE
1	4 yds	45	JACKET	-0.19	1.44	-0.13	0.75	0.00	0.00
			CORE	3.09	-2.84	3.78	-3.63	0.00	20.49
2	4 yds	45	JACKET	-0.47	-0.81	-1.06	-0.88	0.00	0.00
			CORE	-1.09	-0.34	-1.41	-0.31	0.00	0.00
3	4 yds	45	JACKET	-0.81	0.31	-0.59	0.00	0.00	0.00
			CORE	3.06	0.25	3.84	0.38	0.00	22.39

APPENDIX A (CONTINUED). MINIMUM STABILITY DATA

SHOT	MUZZLE TO GLASS DISTANCE	GLASS ANGLE	FRAGMENT	INCHES OF TARGET X DEFLECT	INCHES OF TARGET Y DEFLECT	INCHES OF PLYWOOD X DEFLECT	INCHES OF PLYWOOD Y DEFLECT	DEGREES TARGET TUMBLE	DEGREES PLYWOOD TUMBLE
1	25 yds	90	BULLET	0.56	-0.38	0.59	-0.53	0.00	0.00
2	25 yds	90	BULLET	1.25	0.00	1.63	-0.41	24.60	0.00
3	25 yds	90	BULLET	0.31	0.63	0.41	0.69	0.00	0.00
1	25 yds	60	JACKET CORE	0.44 1.47	0.47 -1.47	0.53 1.84	0.19 -2.13	0.00 48.60	0.00 19.50
2	25 yds	60	JACKET CORE	0.50 1.88	0.00 -0.13	0.66 3.09	-0.13 -0.22	0.00 0.00	0.00 28.10
3	25 yds	60	JACKET CORE	0.28 1.16	-0.84 -0.31	0.44 1.53	-0.75 -0.47	0.00 0.00	0.00 0.00
1	25 yds	45	JACKET CORE	1.72 2.03	-0.97 -0.16	2.34 2.38	-2.78 -0.31	0.00 0.00	0.00 0.00
2	25 yds	45	JACKET CORE	-1.34 4.34	0.44 0.25	-2.06 5.25	0.75 0.00	0.00 0.00	0.00 0.00
3	25 yds	45	JACKET CORE	2.44 3.25	-0.97 0.00	1.72 5.13	-1.16 -0.22	0.00 0.00	0.00 36.90

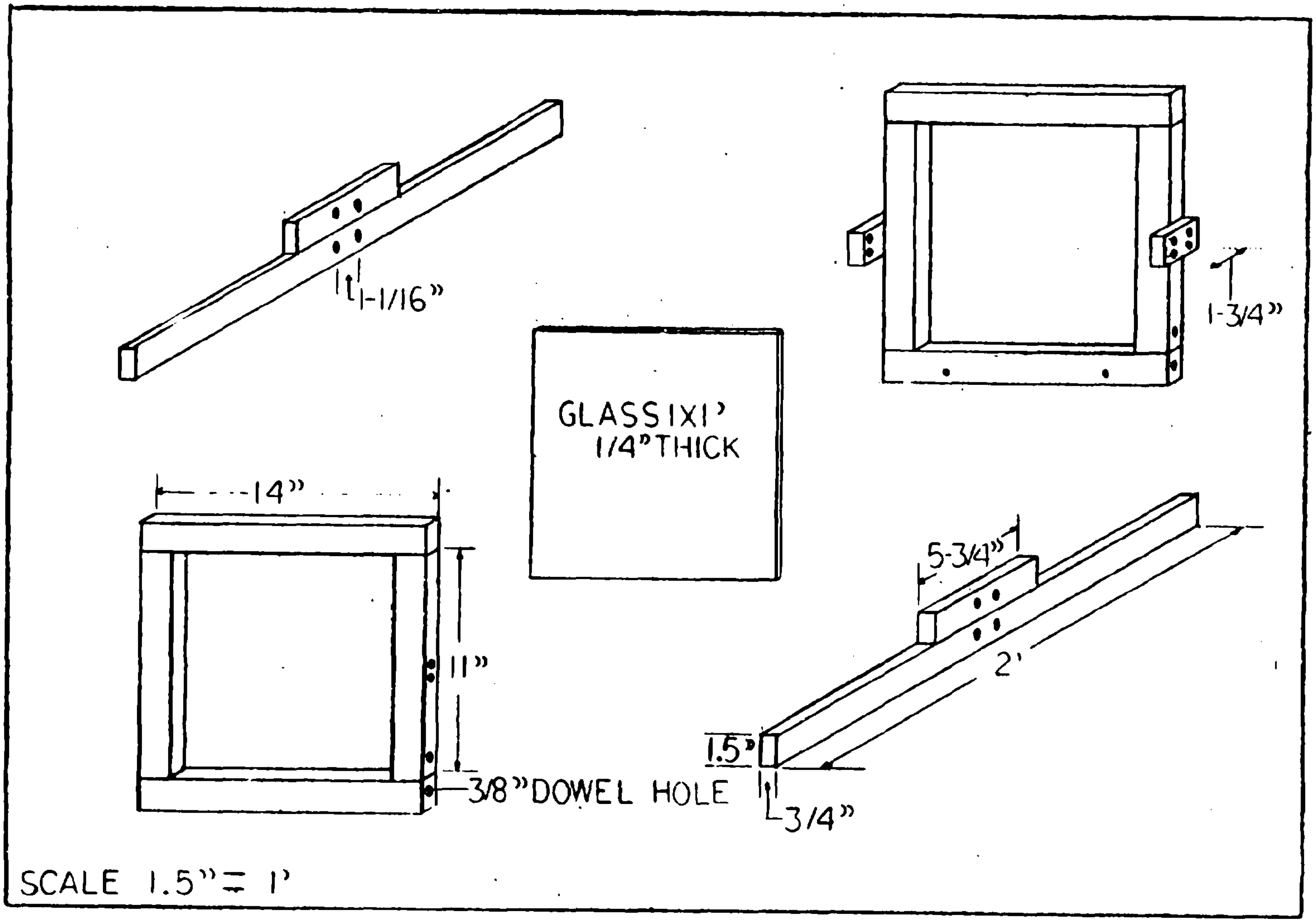
APPENDIX B. 25 YARD DATA

SHOT	MUZZLE TO GLASS DISTANCE	GLASS ANGLE	FRAGMENT	INCHES OF TARGET X DEFLECT	INCHES OF TARGET Y DEFLECT	INCHES OF PLYWOOD X DEFLECT	INCHES OF PLYWOOD Y DEFLECT	DEGREES TARGET TUMBLE	DEGREES PLYWOOD TUMBLE
1	50yds	90	BULLET	0.97	0.34	0.94	0.00	0.00	0.00
2	50 yds	90	BULLET	1.31	-0.25	1.13	-0.66	0.00	23.04
3	50 yds	90	BULLET	-0.31	-0.16	-0.38	-0.38	0.00	30.00
1	50 yds	60	JACKET CORE	-1.88 0.44	0.00 -0.66	-2.38 0.47	-0.34 -1.13	24 [illegible] 2 [illegible] 3	24.90 30.00
2	50 yds	60	BULLET	-0.44	-0.22	-0.47	-0.22	[illegible].00	24.90
3	50 yds	60	JACKET CORE	1.16 2.09	0.22 -0.78	1.38 2.56	-0.22 -0.68	0.00 31.97	0.00 0.00
1	50 yds	45	JACKET CORE	-1.44 1.89	-0.88 1.81	-0.34 1.91	-0.84 3.34	0.00 21.62	0.00 0.00
2	50 yds	45	JACKET CORE	-0.91 4.03	0.97 -0.59	-0.22 4.50	0.63 1.19	0.00 20.49	0.00 0.00
3	50 yds	45	JACKET CORE	-0.66 1.59	1.97 -0.75	-0.41 2.09	2.00 -0.78	0.00 22.39	0.00 31.97

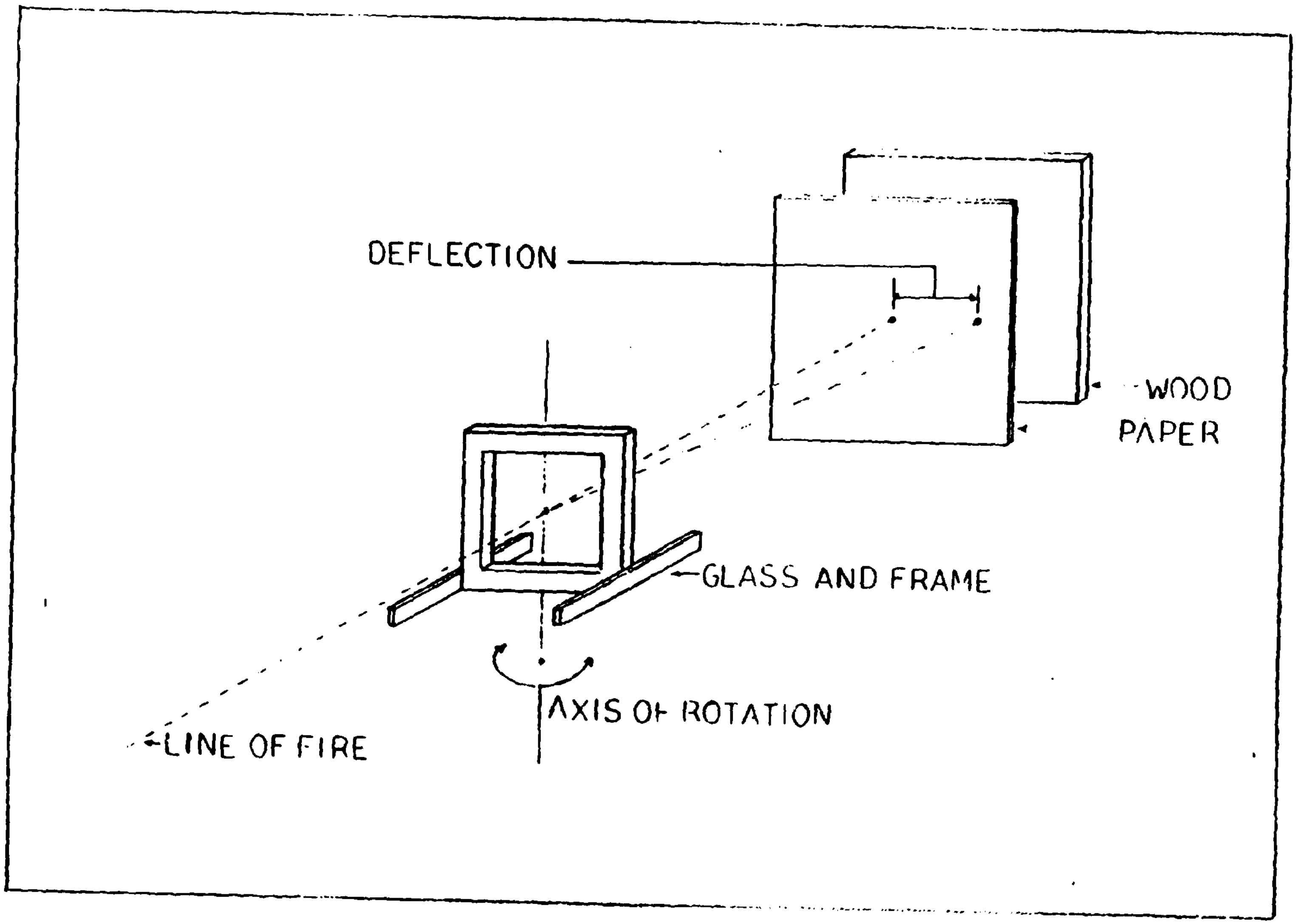
APPENDIX C. 50 YARD DATA

SHOT	MUZZLE TO GLASS DISTANCE	GLASS ANGLE	FRAGMENT	INCHES OF TARGET X DEFLECT	INCHES OF TARGET Y DEFLECT	INCHES OF PLYWOOD X DEFLECT	INCHES OF PLYWOOD Y DEFLECT	DEGREES TARGET TUMBLE	DEGREES PLYWOOD TUMBLE
1	99 yds	90	BULLET	-0.28	1.47	-0.25	1.53	0.00	0.00
2	99 yds	90	BULLET	0.63	-0.84	0.66	-0.84	0.00	0.00
3	99 yds	90	BULLET	0.91	-0.44	0.91	-0.44	0.00	0.00
1	99 yds	60	JACKET CORE	-1.09 2.03	21.53 0.47	-0.84 2.25	0.97 -0.16	0.00 20.49	0.00 24.32
2	99 yds	60	JACKET CORE	-1.47 2.63	0.69 0.25	-0.66 3.19	1.44 -0.16	22.02 0.00	24.90 22.39
3	99 yds	60	JACKET CORE	0.47 0.41	0.97 -0.47	0.88 0.28	0.53 -0.88	0.00 0.00	0.00 20.48
1	99 yds	45	JACKET CORE	1.28 1.53	-3.22 2.41	1.16 2.19	-3.19 3.13	0.00 19.47	0.00 22.89
2	99 yds	45	JACKET CORE	1.00 2.13	-0.38 2.34	1.22 2.75	-0.44 2.75	0.00 30.00	0.00 0.00
3	99 yds	45	JACKET CORE	1.69 0.00	-1.81 1.84	2.25 0.00	-2.03 2.25	0.00 30.00	0.00 0.00

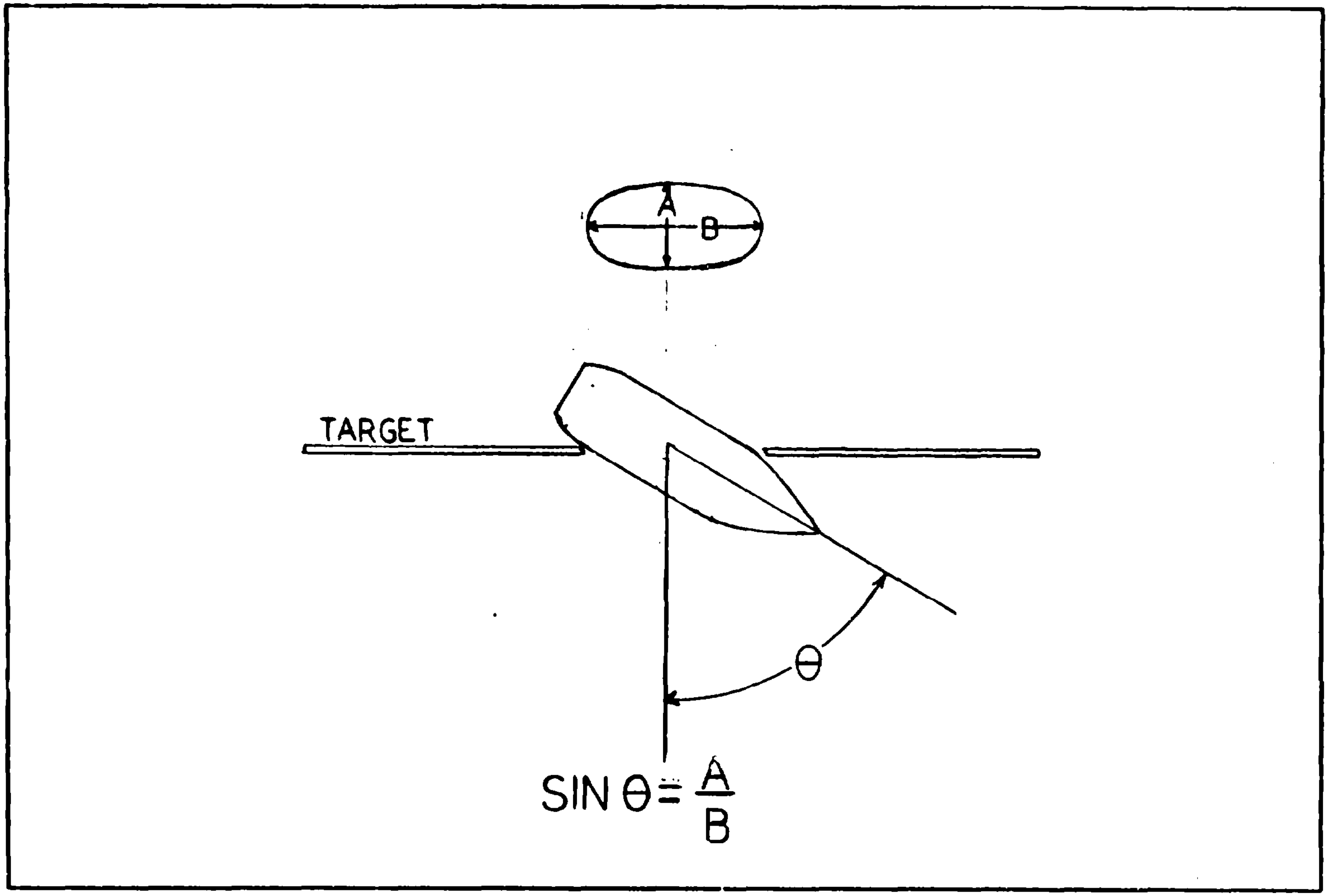
APPENDIX D. 99 YARD DATA



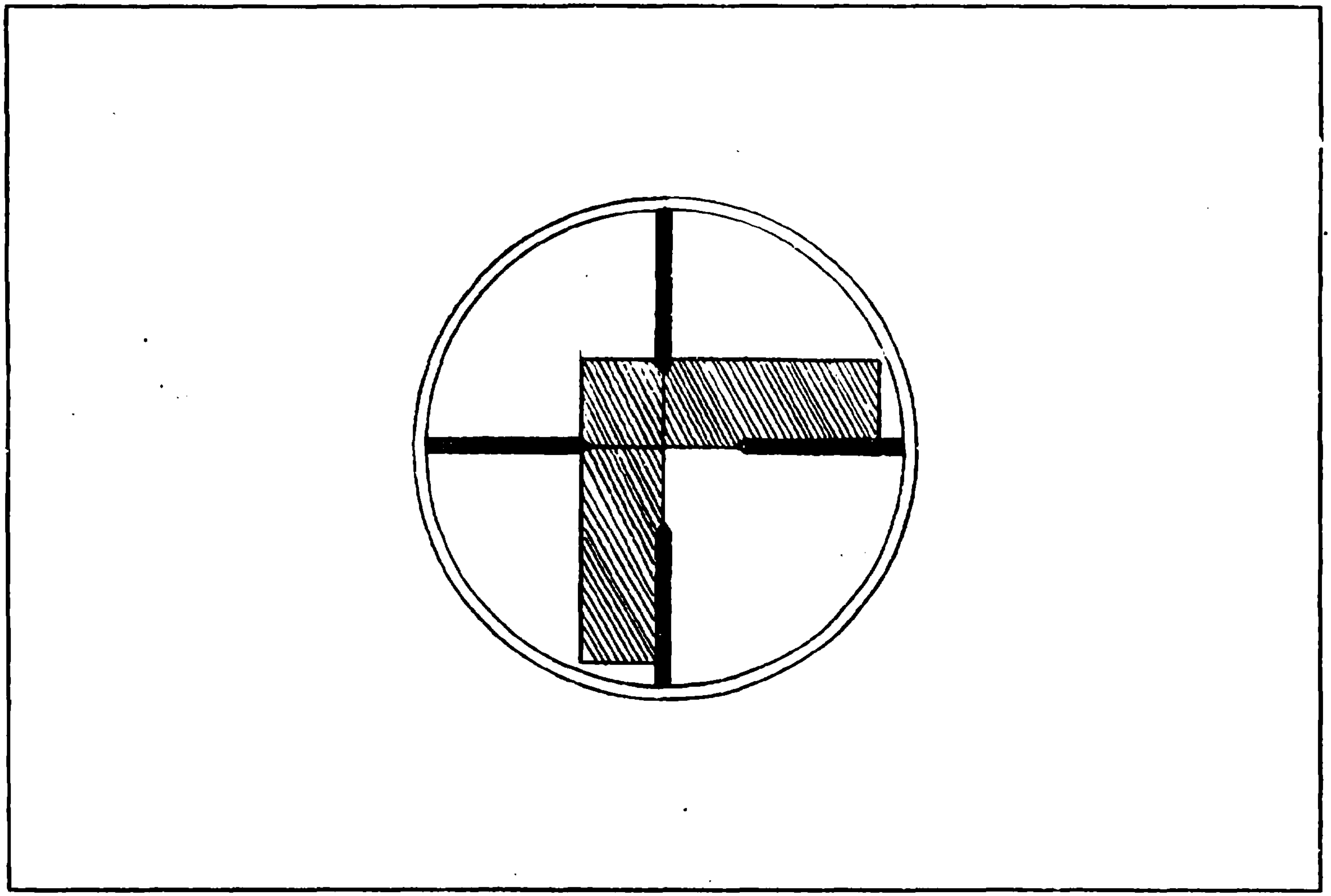
Appendix E. Frame



Appendix F. Test Set-Up



Appendix G. Tumble



Appendix H. Sighting Method

SHOT	MUZZLE TO GLASS DISTANCE	GLASS ANGLE	FRAGMENT	INCHES OF TARGET X DEFLECT	INCHES OF TARGET Y DEFLECT	INCHES OF PLYWOOD X DEFLECT	INCHES OF PLYWOOD Y DEFLECT	DEGREES TARGET TUMBLE	DEGREES PLYWOOD TUMBLE
1	25 yds	60	JACKET CORE	0.34 -1.94	0.69 -0.22	0.81 -2.34	0.44 0.06	0.00 0.00	0.00 0.00
2	25 yds	60	JACKET CORE	-0.94 1.44	-0.56 1.16	-1.31 1.88	-0.53 1.50	0.00 19.47	0.00 0.00
3	25 yds	60	JACKET CORE	0.34 0.22	0.13 -0.84	0.41 0.13	-0.19 -1.06	0.00 0.00	0.00 0.00
1	25 yds	45	JACKET CORE	-0.34 0.25	0.00 -1.84	-0.13 0.00	0.00 -2.00	0.00 0.00	0.00 0.00
2	25 yds	45	JACKET CORE	-1.78 -0.50	2.94 -2.50	4.19 -0.81	-1.84 -2.75	0.00 24.90	0.00 16.60
3	25 yds	45	JACKET CORE	-3.72 2.34	0.28 -1.00	-4.00 3.75	1.34 -1.19	0.00 0.00	0.00 20.49

APPENDIX I. DATA LEFT OF NORMAL

END
FILMED

DATE: 9-94

DTIC